Amazon Braket PennyLane Plugin Documentation

Release 1.24.2

Amazon.com Inc.

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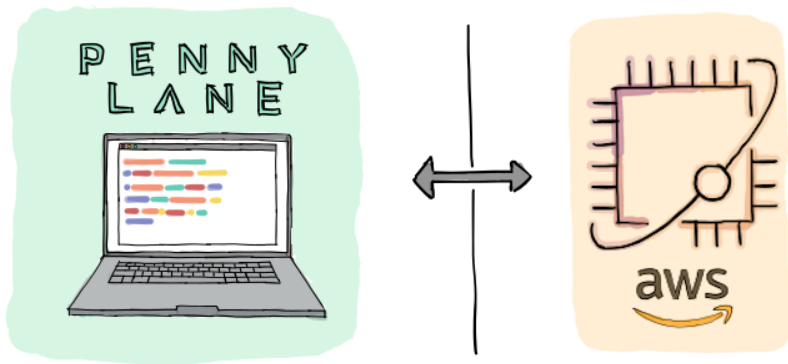
Release
1.24.2



The Amazon Braket Python SDK is an open source library that provides a framework to interact with quantum computing hardware devices and simulators through Amazon Braket.

PennyLane is a machine learning library for optimization and automatic differentiation of hybrid quantum-classical computations.

Once the Pennylane-Braket plugin is installed, the provided Braket devices can be accessed straight away in PennyLane, without the need to import any additional packages.

CHAPTER

ONE

DEVICES

This plugin provides four Braket devices for use with PennyLane - two supporting gate-based computations, and two supporting analog Hamiltonian simulation (AHS):

While the local device helps with small-scale simulations and rapid prototyping, the remote device allows you to run larger simulations or access quantum hardware via the Amazon Braket service.

CHAPTER

TWO

TUTORIALS

To see the PennyLane-Braket plugin in action, you can use any of the qubit-based demos from the PennyLane documentation, for example the tutorial on qubit rotation, and simply replace `'default.qubit'` with the `'braket.local.qubit'` or the `'braket.aws.qubit'` device:

```
dev = qml.device('braket.XXX.qubit', [...])
```

Tutorials that showcase the Braket devices can be found on the PennyLane website and the Amazon Braket examples GitHub repository.

2.1 Installation

Before you begin working with the Amazon Braket PennyLane Plugin, make sure that you installed or configured the following prerequisites:

- Download and install Python 3.9 or greater. If you are using Windows, choose the option *Add Python to environment variables* before you begin the installation.
- Make sure that your AWS account is onboarded to Amazon Braket, as per the instructions here.
- Download and install PennyLane:

  ```
  pip install pennylane
  ```

You can then install the latest release of the PennyLane-Braket plugin as follows:

```
pip install amazon-braket-pennylane-plugin
```

You can also install the development version from source by cloning this repository and running a pip install command in the root directory of the repository:

```
git clone https://github.com/amazon-braket/amazon-braket-pennylane-plugin-python.git
cd amazon-braket-pennylane-plugin-python
pip install .
```

You can check your currently installed version of `amazon-braket-pennylane-plugin` with `pip show`:

```
pip show amazon-braket-pennylane-plugin
```

or alternatively from within Python:

```
from braket import pennylane_plugin
pennylane_plugin.__version__
```

2.1.1 Tests

Make sure to install test dependencies first:

```
pip install -e "amazon-braket-pennylane-plugin-python[test]"
```

Unit tests

Run the unit tests using:

```
tox -e unit-tests
```

To run an individual test:

```
tox -e unit-tests -- -k 'your_test'
```

To run linters and unit tests:

```
tox
```

Integration tests

To run the integration tests, set the `AWS_PROFILE` as explained in the amazon-braket-sdk-python README:

```
export AWS_PROFILE=Your_Profile_Name
```

Running the integration tests creates an S3 bucket in the same account as the `AWS_PROFILE` with the following naming convention `amazon-braket-pennylane-plugin-integ-tests-{account_id}`.

Run the integration tests with:

```
tox -e integ-tests
```

To run an individual integration test:

```
tox -e integ-tests -- -k 'your_test'
```

2.1.2 Documentation

To build the HTML documentation, run:

```
tox -e docs
```

The documentation can then be found in the `doc/build/documentation/html/` directory.

2.2 Support

- **Source Code:** https://github.com/amazon-braket/amazon-braket-pennylane-plugin-python
- **Issue Tracker:** https://github.com/amazon-braket/amazon-braket-pennylane-plugin-python/issues
- **General Questions:** https://quantumcomputing.stackexchange.com/questions/ask (add the tag amazon-braket)
- **PennyLane Forum:** https://discuss.pennylane.ai

If you are having issues, please let us know by posting the issue on our Github issue tracker, or by asking a question in the forum.

2.3 The remote Braket device

The remote qubit device of the PennyLane-Braket plugin runs gate-based quantum computations on Amazon Braket's remote service. The remote service provides access to hardware providers and a high-performance simulator backend.

A list of available quantum devices and their features can be found in the Amazon Braket Developer Guide.

2.3.1 Usage

After the Braket SDK and the plugin are installed, and once you sign up for Amazon Braket, you have access to the remote Braket device in PennyLane.

Instantiate an AWS device that communicates with the Braket service like this:

```
>>> import pennylane as qml
>>> s3 = ("my-bucket", "my-prefix")
>>> remote_device = qml.device("braket.aws.qubit", device_arn="arn:aws:braket:::device/
↪quantum-simulator/amazon/sv1", s3_destination_folder=s3, wires=2)
```

In this example, the string `arn:aws:braket:::device/quantum-simulator/amazon/sv1` is the ARN that identifies the SV1 device. Other supported devices and their ARNs can be found in the Amazon Braket Developer Guide. Note that the plugin works with digital (qubit) gate-based devices only.

This device can then be used just like other devices for the definition and evaluation of QNodes within PennyLane.

For example:

```
@qml.qnode(remote_device)
def circuit(x, y, z):
    qml.RZ(z, wires=[0])
    qml.RY(y, wires=[0])
    qml.RX(x, wires=[0])
    qml.CNOT(wires=[0, 1])
    return qml.expval(qml.PauliZ(0)), var(qml.PauliZ(1))
```

When executed, the circuit performs the computation on the Amazon Braket service.

```
>>> circuit(0.2, 0.1, 0.3)
array([0.97517033, 0.04904283])
```

2.3.2 Enabling the parallel execution of multiple circuits

Where supported by the backend of the Amazon Braket service, the remote device can be used to execute multiple quantum circuits in parallel. To unlock this feature, instantiate the device using the `parallel=True` argument:

```
>>> remote_device = qml.device('braket.aws.qubit', [... ,] parallel=True)
```

The details of the parallelization scheme depend on the PennyLane version you use, as well as your AWS account specifications.

For example, PennyLane 0.13.0 and higher supports the parallel execution of circuits created during the computation of gradients. Just by instantiating the remote device with the `parallel=True` option, this feature is automatically used and can lead to significant speedups of your optimization pipeline.

The maximum number of circuits that can be executed in parallel is specified by the `max_parallel` argument.

```
>>> remote_device = qml.device('braket.aws.qubit', [... ,] parallel=True, max_
↪parallel=20)
```

Make sure that this number is not larger than the maximum number of concurrent tasks allowed for your account on the backend you choose. See the Braket developer guide for more details.

The Braket remote device has the capability to retry failed circuit executions, up to 3 times per circuit by default. You can set a timeout by using the `poll_timeout_seconds` argument; the device will retry circuits that do not complete within the timeout. A timeout of 30 to 60 seconds is recommended for circuits with fewer than 25 qubits.

2.3.3 Device options

The default value of the `shots` argument is `Shots.DEFAULT`, resulting in the default number of shots specified by the remote device being used. For example, a simulator device may default to analytic mode while a QPU must pick a finite number of shots.

Setting `shots=0` or `shots=None` will cause the device to run in analytic mode. If the device ARN points to a QPU, analytic mode is not available and an error will be raised.

2.3.4 Supported operations

The operations supported by this device vary based on the operations supported by the underlying Braket device. To check the device's supported operations, run

```
dev.operations
```

In addition to those provided by PennyLane, the PennyLane-Braket plugin provides the following framework-specific operations, which can be imported from `braket.pennylane_plugin.ops`:

braket.pennylane_plugin.CPhaseShift00(phi, wires)	Controlled phase shift gate phasing the $\|00\rangle$ state.
braket.pennylane_plugin.CPhaseShift01(phi, wires)	Controlled phase shift gate phasing the $\|01\rangle$ state.
braket.pennylane_plugin.CPhaseShift10(phi, wires)	Controlled phase shift gate phasing the $\|10\rangle$ state.
braket.pennylane_plugin.PSWAP(phi, wires)	Phase-SWAP gate.
braket.pennylane_plugin.GPi(phi, wires)	IonQ native GPi gate.
braket.pennylane_plugin.GPi2(phi, wires)	IonQ native GPi2 gate.
braket.pennylane_plugin.MS(phi_0, phi_1, wires)	IonQ native Mølmer-Sørenson gate.

2.3.5 Pulse Programming

The PennyLane-Braket plugin provides pulse-level control for the OQC Lucy QPU through PennyLane's ParametrizedEvolution operation. Compatible pulse Hamiltonians can be defined using the qml.pulse.transmon_drive function and used to create `ParametrizedEvolution`'s using qml.evolve:

```
duration = 15
def amp(p, t):
    return qml.pulse.pwc(duration)(p, t)

dev = qml.device("braket.aws.qubit", wires=8, device_arn="arn:aws:braket:eu-west-
↪2::device/qpu/oqc/Lucy")

drive = qml.pulse.transmon.transmon_drive(amplitude=amp, phase=0, freq=4.8, wires=[0])

@qml.qnode(dev)
def circuit(params, t):
    qml.evolve(drive)(params, t)
    return qml.expval(qml.PauliZ(wires=0))
```

Note that the `freq` argument of `qml.pulse.transmon_drive` is specified in GHz, and for hardware upload the amplitude will be interpreted as an output power for control hardware in volts. The `phase` must be specified in radians.

The pulse settings for the device can be obtained using the `pulse_settings` property. These settings can be used to describe the transmon interaction Hamiltonian using qml.pulse.transmon_interaction:

```
dev = qml.device("braket.aws.qubit", wires=8, device_arn="arn:aws:braket:eu-
↪west-2::device/qpu/oqc/Lucy")
pulse_settings = dev.pulse_settings
couplings = [0.01]*len(connections)
H = qml.pulse.transmon_interaction(**pulse_settings, coupling=couplings)
```

By passing `pulse_settings` from the remote device to `qml.pulse.transmon_interaction`, an `H` Hamiltonian term is created using the constants specific to the hardware. This is relevant for simulating the hardware in PennyLane on the `default.qubit` device.

Note that the user must supply coupling coefficients, as these are not available from the hardware backend. On the order of 10 MHz (0.01 GHz) is in a realistic range.

2.3.6 Gradient computation on Braket with a QAOA Hamiltonian

Currently, PennyLane will compute grouping indices for QAOA Hamiltonians and use them to split the Hamiltonian into multiple expectation values. If you wish to use SV1's adjoint differentiation capability when running QAOA from PennyLane, you will need reconstruct the cost Hamiltonian to remove the grouping indices from the cost Hamiltonian, like so:

```
cost_h, mixer_h = qml.qaoa.max_clique(g, constrained=False)
cost_h = qml.Hamiltonian(cost_h.coeffs, cost_h.ops)
```

2.4 The local Braket device

The local qubit device of the PennyLane-Braket plugin runs gate-based quantum computations on the local Braket SDK. This could be either utilizing the processors of your own PC, or those of a Braket notebook instance hosted on AWS.

This device is useful for small-scale simulations in which the time of sending a job to a remote service would add an unnecessary overhead. It can also be used for rapid prototyping before running a computation on a paid-for remote service.

2.4.1 Usage

After the Braket SDK and the plugin are installed you immediately have access to the local Braket device in PennyLane.

To instantiate the local Braket simulator, simply use:

```
import pennylane as qml
device_local = qml.device("braket.local.qubit", wires=2) # local state vector simulator
# device_local = qml.device("braket.local.qubit", backend="default", wires=2) # local␣
↪state vector simulator
# device_local = qml.device("braket.local.qubit", backend="braket_sv", wires=2) # local␣
↪state vector simulator
# device_local = qml.device("braket.local.qubit", backend="braket_dm", wires=2) # local␣
↪state vector simulator
```

You can define and evaluate quantum nodes with these devices just as you would with any other PennyLane device.

For example:

```
@qml.qnode(device_local)
def circuit(x, y, z):
    qml.RZ(z, wires=[0])
    qml.RY(y, wires=[0])
    qml.RX(x, wires=[0])
    qml.CNOT(wires=[0, 1])
    return qml.expval(qml.PauliZ(0)), var(qml.PauliZ(1))
```

When executed, the circuit will perform the computation on the local machine.

```
>>> circuit(0.2, 0.1, 0.3)
array([0.97517033, 0.04904283])
```

2.4.2 Device options

You can set shots to None (default) to get exact results instead of results calculated from samples.

2.4.3 Supported operations

The operations supported by this device vary based on the operations supported by the underlying Braket device. To check the device's supported operations, run

```
dev.operations
```

In addition to those provided by PennyLane, the PennyLane-Braket plugin provides the following framework-specific operations, which can be imported from braket.pennylane_plugin.ops:

braket.pennylane_plugin.CPhaseShift00(phi, wires)	Controlled phase shift gate phasing the $\|00\rangle$ state.
braket.pennylane_plugin.CPhaseShift01(phi, wires)	Controlled phase shift gate phasing the $\|01\rangle$ state.
braket.pennylane_plugin.CPhaseShift10(phi, wires)	Controlled phase shift gate phasing the $\|10\rangle$ state.
braket.pennylane_plugin.PSWAP(phi, wires)	Phase-SWAP gate.
braket.pennylane_plugin.GPi(phi, wires)	IonQ native GPi gate.
braket.pennylane_plugin.GPi2(phi, wires)	IonQ native GPi2 gate.
braket.pennylane_plugin.MS(phi_0, phi_1, wires)	IonQ native Mølmer-Sørenson gate.

2.5 The local AHS device

The local analog Hamiltonian simulation (AHS) device of the PennyLane-Braket plugin runs simulation on the local Braket SDK. This could be either utilizing the processors of your own PC, or those of a Braket notebook instance hosted on AWS.

This device is useful for small-scale simulations in which the time of sending a job to a remote service would add an unnecessary overhead. It can also be used for rapid prototyping before running a computation on a paid-for remote service.

2.5.1 Usage

After the Braket SDK and the plugin are installed you immediately have access to the local Braket AHS simulator in PennyLane.

The local AHS device is not gate-based. Instead, it is compatible with the ParametrizedEvolution operator from pulse programming in PennyLane.

Note that pulse programming in PennyLane requires the module jax, which can be installed following the instructions [here](https://github.com/google/jax#installation).

To instantiate the local Braket simulator, simply use:

```
import pennylane as qml
device_local = qml.device("braket.local.ahs", wires=2)
```

This device can be used with a QNode within PennyLane. It accepts circuits with a single ParametrizedEvolution operator based on a ParametrizedHamiltonian compatible with the simulated hardware. More information about creating PennyLane operators for AHS can be found in the PennyLane docs.

Note: It is important to keep track of units when specifying electromagnetic pulses for hardware control. The frequency and amplitude provided in PennyLane for Rydberg atom systems are expected to be in units of MHz, time in microseconds, phase in radians, and distance in micrometers. All of these will be converted to SI units internally as needed for upload to the hardware, and frequency will be converted to angular frequency (multiplied by 2π).

When reading hardware specifications from the Braket backend, bear in mind that all units are SI and frequencies are in rad/s. This conversion is done when creating a pulse program for upload, and units in the PennyLane functions should follow the conventions specified in the PennyLane docs to ensure correct unit conversion. See rydberg_interaction and rydberg_drive in Pennylane for specification of expected input units, and examples for creating hardware-compatible ParametrizedEvolution operators in PennyLane.

Creating a register

The atom register defines where the atoms will be located, which determines the strength of the interaction between the atoms. Here we define coordinates for the atoms to be placed at (in micrometers), and create a constant interaction term for the Hamiltonian:

```
# number of coordinate pairs must match number of device wires
coordinates = [[0, 0], [0, 5]]

H_interaction = qml.pulse.rydberg_interaction(coordinates)
```

Creating a drive

We can create a drive with a global component and (positive) local detunings. If the local detunings are time-dependent, they must all have the same time-dependent envelope, but can have different, positive scaling factors.

```
from jax import numpy as jnp

# gaussian amplitude function (qml.pulse.rect enforces 0 at start and end for hardware)
def amp_fn(p, t):
    f = p[0] * jnp.exp(-(t - p[1])**2 / (2 * p[2]**2))
    return qml.pulse.rect(f, windows=[0.1, 1.7])(p, t)

# defining a linear detuning
def det_fn_global(p, t):
    return p * t

def det_fn_local(p, t):
    return p * t**2

# creating a global drive on all wires
H_global = qml.pulse.rydberg_drive(amplitude=amp_fn, phase=0, detuning=det_fn_global,␣
↪wires=[0, 1])

# creating local drives
# note only local detuning is currently supported, so amplitude and phase are set to 0
```

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```
H_local0 = qml.pulse.rydberg_drive(amplitude=0, phase=0, detuning = det_fn_local,␣
↪wires=[0])
H_local1 = qml.pulse.rydberg_drive(amplitude=0, phase=0, detuning = det_fn_local,␣
↪wires=[1])

# full hamiltonian
H = H_interaction + H_global + H_local0 + H_local1
```

Executing an AHS program

```
@qml.qnode(device_local)
def circuit(params):
    qml.evolve(H)(params, t=1.5)
    return qml.sample()

# amp_fn expects p to contain 3 parameters
amp_params = [2.5, 1, 0.3]
# global_det_fn expects p to be a single parameter
det_global_params = 0.2
# each of the local drives take a single parameter for p
# the detunings have the same shape, but vary by scaling factor p
local_params1 = 0.5
local_params2 = 1
```

When executed, the circuit will perform the computation on the local machine.

```
>>> circuit([amp_params, det_global_params, local_params1, local_params2])
array([[0, 0],
       [0, 0],
       [0, 0],
       ...,
       [1, 0],
       [1, 0],
       [1, 0]])
```

2.6 The remote AHS device

The remote AHS device of the PennyLane-Braket plugin runs analog Hamiltonian simulation (AHS) on Amazon Braket's remote service. AHS is a quantum computing paradigm different from gate-based computing. AHS uses a well-controlled quantum system and tunes its parameters to mimic the dynamics of another quantum system, the one we aim to study.

The remote service provides access to running AHS on hardware. As AHS devices are not gate-based, they are not compatible with the standard PennyLane operators. Instead, they are compatible with pulse programming in PennyLane.

Note that pulse programming in PennyLane requires the module `jax`, which can be installed following the instructions [here](https://github.com/google/jax#installation).

More information about AHS and the capabilities of the hardware can be found in the Amazon Braket Developer Guide.

2.6.1 Usage

After the Braket SDK and the plugin are installed, and once you sign up for Amazon Braket, you have access to the remote AHS device in PennyLane.

Instantiate an AWS device that communicates with the hardware like this:

```
>>> import pennylane as qml
>>> device_arn = "arn:aws:braket:us-east-1::device/qpu/quera/Aquila"
>>> remote_device = qml.device("braket.aws.ahs", device_arn=device_arn, wires=3)
```

This device can be used with a QNode within PennyLane. It accepts circuits with a single ParametrizedEvolution operator based on a hardware-compatible ParametrizedHamiltonian. More information about creating PennyLane operators for AHS can be found in the PennyLane docs.

Note: It is important to keep track of units when specifying electromagnetic pulses for hardware control. The frequency and amplitude provided in PennyLane for Rydberg atom systems are expected to be in units of MHz, time in microseconds, phase in radians, and distance in micrometers. All of these will be converted to SI units internally as needed for upload to the hardware, and frequency will be converted to angular frequency (multiplied by 2π).

When reading hardware specifications from the Braket backend, bear in mind that all units are SI and frequencies are in rad/s. This conversion is done when creating a pulse program for upload, and units in the PennyLane functions should follow the conventions specified in the PennyLane docs to ensure correct unit conversion. See rydberg_interaction and rydberg_drive in Pennylane for specification of expected input units, and examples for creating hardware-compatible ParametrizedEvolution operators in PennyLane.

Creating a register

The atom register defines where the atoms will be located, and determines the strength of the interaction between the atoms. Here we define coordinates for the atoms to be placed at (in micrometers), and create a constant interaction term for the Hamiltonian:

```
# number of coordinate pairs must match number of device wires
coordinates = [[0, 0], [0, 5], [5, 0]]

H_interaction = qml.pulse.rydberg_interaction(coordinates)
```

Creating a global drive

Hardware currently only supports a single global drive pulse applied to all atoms in the register.

Here we define a global drive with time dependent amplitude and detuning, with phase set to 0.

```
from jax import numpy as jnp

# gaussian amplitude function (qml.pulse.rect enforces 0 at start and end for hardware)
def amp_fn(p, t):
    f = p[0] * jnp.exp(-(t - p[1])**2 / (2 * p[2]**2))
    return qml.pulse.rect(f, windows=[0.1, 1.7])(p, t)


# defining a linear detuning
```

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```
def det_fn(p, t):
    return p * t

# creating a global drive on all wires
H_global = qml.pulse.rydberg_drive(amplitude=amp_fn, phase=0, detuning=det_fn, wires=[0,␣
↪1, 2])
```

Creating and executing the circuit

Once we have the terms describing the atomic interactions and the electromagnetic drive on the atoms, we can create and execute a circuit to run the pulse program on the hardware:

```
@qml.qnode(remote_device)
def circuit(amp_params, det_params):
    qml.evolve(H_interaction + H_global)([amp_params, det_params], t=1.75)
    return qml.sample()
```

When executed, the circuit performs the computation on the hardware.

```
>>> amp_params = [2.5, 1, 0.3]  # amp_fn expects p to contain 3 parameters
>>> det_params = 0.2  # det_fn expects p to be a single parameter
>>> circuit(amp_params, det_params)
array([0.97517033, 0.04904283])
```

2.6.2 Device options

The default value of the `shots` argument is `Shots.DEFAULT`, resulting in the default number of shots specified by the remote device being used. For example, a simulator device may default to analytic mode while a QPU must pick a finite number of shots.

This device is not compatible with analytic mode, so an error will be raised if `shots=0` or `shots=None`.

2.6.3 Supported operations

The only operation supported for analog Hamiltonian simulation is a ParametrizedEvolution describing a hardware-compatible electromagnetic pulse.

2.7 pennylane-braket

This section contains the API documentation for the PennyLane-Braket plugin.

> **Warning:** Unless you are a PennyLane plugin developer, you likely do not need to use these classes and functions directly.
>
> See the *overview* page for more details using the available Braket devices with PennyLane.

2.7.1 Classes

AAMS(phi_0, phi_1, theta, wires)	IonQ native Arbitrary-Angle Mølmer-Sørenson gate.
BraketAwsAhsDevice(wires, device_arn[, ...])	Amazon Braket AHS device for hardware in PennyLane.
BraketAwsQubitDevice(wires, device_arn[, ...])	Amazon Braket AwsDevice qubit device for PennyLane.
BraketLocalAhsDevice(wires, *[, shots])	Amazon Braket LocalSimulator AHS device for PennyLane.
BraketLocalQubitDevice(wires[, backend, shots])	Amazon Braket LocalSimulator qubit device for PennyLane.
CPhaseShift00(phi, wires)	Controlled phase shift gate phasing the $\|00\rangle$ state.
CPhaseShift01(phi, wires)	Controlled phase shift gate phasing the $\|01\rangle$ state.
CPhaseShift10(phi, wires)	Controlled phase shift gate phasing the $\|10\rangle$ state.
GPi(phi, wires)	IonQ native GPi gate.
GPi2(phi, wires)	IonQ native GPi2 gate.
MS(phi_0, phi_1, wires)	IonQ native Mølmer-Sørenson gate.
PSWAP(phi, wires)	Phase-SWAP gate.

AAMS

class AAMS(*phi_0*, *phi_1*, *theta*, *wires*)

Bases: `Operation`

IonQ native Arbitrary-Angle Mølmer-Sørenson gate.

$$\mathtt{MS}(\phi_0, \phi_1, \theta) = \begin{bmatrix} \cos\frac{\theta}{2} & 0 & 0 & -ie^{-i(\phi_0+\phi_1)}\sin\frac{\theta}{2} \\ 0 & \cos\frac{\theta}{2} & -ie^{-i(\phi_0-\phi_1)}\sin\frac{\theta}{2} & 0 \\ 0 & -ie^{i(\phi_0-\phi_1)}\sin\frac{\theta}{2} & \cos\frac{\theta}{2} & 0 \\ -ie^{i(\phi_0+\phi_1)}\sin\frac{\theta}{2} & 0 & 0 & \cos\frac{\theta}{2} \end{bmatrix}.$$

Details:

- Number of wires: 2
- Number of parameters: 2

Parameters

- **phi_0** (*float*) – the first phase angle
- **phi_1** (*float*) – the second phase angle
- **theta** (*float*) – the entangling angle
- **wires** (*int*) – the subsystem the gate acts on
- **id** (*str or None*) – String representing the operation (optional)

arithmetic_depth	Arithmetic depth of the operator.
basis	The basis of an operation, or for controlled gates, of the target operation.
batch_size	Batch size of the operator if it is used with broadcasted parameters.
control_wires	Control wires of the operator.
grad_method	
grad_recipe	Gradient recipe for the parameter-shift method.
has_adjoint	
has_decomposition	
has_diagonalizing_gates	
has_generator	
has_matrix	
hash	Integer hash that uniquely represents the operator.
hyperparameters	Dictionary of non-trainable variables that this operation depends on.
id	Custom string to label a specific operator instance.
is_hermitian	This property determines if an operator is hermitian.
name	String for the name of the operator.
ndim_params	Number of dimensions per trainable parameter of the operator.
num_params	
num_wires	Number of wires the operator acts on.
parameter_frequencies	Returns the frequencies for each operator parameter with respect to an expectation value of the form $\langle\psi\vert U(\mathbf{p})^\dagger\hat{O}U(\mathbf{p})\vert\psi\rangle$.
parameters	Trainable parameters that the operator depends on.
pauli_rep	A `PauliSentence` representation of the Operator, or `None` if it doesn't have one.
wires	Wires that the operator acts on.

arithmetic_depth

Arithmetic depth of the operator.

basis

The basis of an operation, or for controlled gates, of the target operation. If not `None`, should take a value of `"X"`, `"Y"`, or `"Z"`.

For example, `X` and `CNOT` have `basis = "X"`, whereas `ControlledPhaseShift` and `RZ` have `basis = "Z"`.

Type

str or None

batch_size

Batch size of the operator if it is used with broadcasted parameters.

The `batch_size` is determined based on `ndim_params` and the provided parameters for the operator. If (some of) the latter have an additional dimension, and this dimension has the same size for all parameters, its size is the batch size of the operator. If no parameter has an additional dimension, the batch size is `None`.

Returns
Size of the parameter broadcasting dimension if present, else `None`.

Return type
int or None

control_wires

Control wires of the operator.

For operations that are not controlled, this is an empty `Wires` object of length `0`.

Returns
The control wires of the operation.

Return type
Wires

grad_method = 'F'

grad_recipe = None

Gradient recipe for the parameter-shift method.

This is a tuple with one nested list per operation parameter. For parameter ϕ_k, the nested list contains elements of the form $[c_i, a_i, s_i]$ where i is the index of the term, resulting in a gradient recipe of

$$\frac{\partial}{\partial \phi_k} f = \sum_i c_i f(a_i \phi_k + s_i).$$

If `None`, the default gradient recipe containing the two terms $[c_0, a_0, s_0] = [1/2, 1, \pi/2]$ and $[c_1, a_1, s_1] = [-1/2, 1, -\pi/2]$ is assumed for every parameter.

Type
tuple(Union(list[list[float]], None)) or None

has_adjoint = True

has_decomposition = False

has_diagonalizing_gates = False

has_generator = False

has_matrix = True

hash

Integer hash that uniquely represents the operator.

Type
int

hyperparameters

Dictionary of non-trainable variables that this operation depends on.

Type
dict

id

Custom string to label a specific operator instance.

is_hermitian

This property determines if an operator is hermitian.

name

String for the name of the operator.

ndim_params

Number of dimensions per trainable parameter of the operator.

By default, this property returns the numbers of dimensions of the parameters used for the operator creation. If the parameter sizes for an operator subclass are fixed, this property can be overwritten to return the fixed value.

Returns
Number of dimensions for each trainable parameter.

Return type
tuple

num_params = 3

num_wires = 2

Number of wires the operator acts on.

parameter_frequencies

Returns the frequencies for each operator parameter with respect to an expectation value of the form $\langle\psi|U(\mathbf{p})^\dagger\hat{O}U(\mathbf{p})|\psi\rangle$.

These frequencies encode the behaviour of the operator $U(\mathbf{p})$ on the value of the expectation value as the parameters are modified. For more details, please see the `pennylane.fourier` module.

Returns
Tuple of frequencies for each parameter. Note that only non-negative frequency values are returned.

Return type
list[tuple[int or float]]

Example

```
>>> op = qml.CRot(0.4, 0.1, 0.3, wires=[0, 1])
>>> op.parameter_frequencies
[(0.5, 1), (0.5, 1), (0.5, 1)]
```

For operators that define a generator, the parameter frequencies are directly related to the eigenvalues of the generator:

```
>>> op = qml.ControlledPhaseShift(0.1, wires=[0, 1])
>>> op.parameter_frequencies
[(1,)]
>>> gen = qml.generator(op, format="observable")
>>> gen_eigvals = qml.eigvals(gen)
>>> qml.gradients.eigvals_to_frequencies(tuple(gen_eigvals))
(1.0,)
```

For more details on this relationship, see `eigvals_to_frequencies()`.

parameters

Trainable parameters that the operator depends on.

pauli_rep

A `PauliSentence` representation of the Operator, or `None` if it doesn't have one.

wires

Wires that the operator acts on.

Returns
wires

Return type
Wires

adjoint()	Create an operation that is the adjoint of this one.
compute_decomposition(*params[, wires])	Representation of the operator as a product of other operators (static method).
compute_diagonalizing_gates(*params, wires, ...)	Sequence of gates that diagonalize the operator in the computational basis (static method).
compute_eigvals(*params, **hyperparams)	Eigenvalues of the operator in the computational basis (static method).
compute_matrix(phi_0, phi_1, theta)	Representation of the operator as a canonical matrix in the computational basis (static method).
compute_sparse_matrix(*params, **hyperparams)	Representation of the operator as a sparse matrix in the computational basis (static method).
decomposition()	Representation of the operator as a product of other operators.
diagonalizing_gates()	Sequence of gates that diagonalize the operator in the computational basis.
eigvals()	Eigenvalues of the operator in the computational basis.
expand()	Returns a tape that contains the decomposition of the operator.
generator()	Generator of an operator that is in single-parameter-form.
label([decimals, base_label, cache])	A customizable string representation of the operator.
map_wires(wire_map)	Returns a copy of the current operator with its wires changed according to the given wire map.
matrix([wire_order])	Representation of the operator as a matrix in the computational basis.
pow(z)	A list of new operators equal to this one raised to the given power.
queue([context])	Append the operator to the Operator queue.
simplify()	Reduce the depth of nested operators to the minimum.
single_qubit_rot_angles()	The parameters required to implement a single-qubit gate as an equivalent `Rot` gate, up to a global phase.
sparse_matrix([wire_order])	Representation of the operator as a sparse matrix in the computational basis.
terms()	Representation of the operator as a linear combination of other operators.
validate_subspace(subspace)	Validate the subspace for qutrit operations.

adjoint()

Create an operation that is the adjoint of this one.

Adjointed operations are the conjugated and transposed version of the original operation. Adjointed ops are equivalent to the inverted operation for unitary gates.

Returns
The adjointed operation.

`static compute_decomposition(*params, wires=None, **hyperparameters)`

Representation of the operator as a product of other operators (static method).

$$O = O_1 O_2 \dots O_n.$$

Note: Operations making up the decomposition should be queued within the `compute_decomposition` method.

See also:

`decomposition()`.

Parameters

- **`*params`** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **`wires`** (*Iterable[Any], Wires*) – wires that the operator acts on
- **`**hyperparams`** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
decomposition of the operator

Return type
list[Operator]

`static compute_diagonalizing_gates(*params, wires, **hyperparams)`

Sequence of gates that diagonalize the operator in the computational basis (static method).

Given the eigendecomposition $O = U\Sigma U^{\dagger}$ where Σ is a diagonal matrix containing the eigenvalues, the sequence of diagonalizing gates implements the unitary $U^{\dagger}$.

The diagonalizing gates rotate the state into the eigenbasis of the operator.

See also:

`diagonalizing_gates()`.

Parameters

- **`params`** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **`wires`** (*Iterable[Any], Wires*) – wires that the operator acts on
- **`hyperparams`** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
list of diagonalizing gates

Return type
list[.Operator]

`static compute_eigvals`(**params*, ***hyperparams*)

Eigenvalues of the operator in the computational basis (static method).

If `diagonalizing_gates` are specified and implement a unitary $U^\dagger$, the operator can be reconstructed as

$$O = U\Sigma U^\dagger,$$

where Σ is the diagonal matrix containing the eigenvalues.

Otherwise, no particular order for the eigenvalues is guaranteed.

See also:

`Operator.eigvals()` and `qml.eigvals()`

Parameters

- **`*params`** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **`**hyperparams`** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
eigenvalues

Return type
tensor_like

`static compute_matrix`(*phi_0*, *phi_1*, *theta*)

Representation of the operator as a canonical matrix in the computational basis (static method).

The canonical matrix is the textbook matrix representation that does not consider wires. Implicitly, this assumes that the wires of the operator correspond to the global wire order.

See also:

`Operator.matrix()` and `qml.matrix()`

Parameters

- **`*params`** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **`**hyperparams`** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
matrix representation

Return type
tensor_like

`static compute_sparse_matrix(*params, **hyperparams)`

Representation of the operator as a sparse matrix in the computational basis (static method).

The canonical matrix is the textbook matrix representation that does not consider wires. Implicitly, this assumes that the wires of the operator correspond to the global wire order.

See also:

`sparse_matrix()`

Parameters

- **`*params`** (`list`) – trainable parameters of the operator, as stored in the `parameters` attribute
- **`**hyperparams`** (`dict`) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
sparse matrix representation

Return type
scipy.sparse._csr.csr_matrix

`decomposition()`

Representation of the operator as a product of other operators.

$$O = O_1 O_2 \ldots O_n$$

A `DecompositionUndefinedError` is raised if no representation by decomposition is defined.

See also:

`compute_decomposition()`.

Returns
decomposition of the operator

Return type
list[Operator]

`diagonalizing_gates()`

Sequence of gates that diagonalize the operator in the computational basis.

Given the eigendecomposition $O = U\Sigma U^{\dagger}$ where Σ is a diagonal matrix containing the eigenvalues, the sequence of diagonalizing gates implements the unitary $U^{\dagger}$.

The diagonalizing gates rotate the state into the eigenbasis of the operator.

A `DiagGatesUndefinedError` is raised if no representation by decomposition is defined.

See also:

`compute_diagonalizing_gates()`.

Returns
a list of operators

Return type
list[.Operator] or None

eigvals()

Eigenvalues of the operator in the computational basis.

If *diagonalizing_gates* are specified and implement a unitary $U^\dagger$, the operator can be reconstructed as

$$O = U\Sigma U^\dagger,$$

where Σ is the diagonal matrix containing the eigenvalues.

Otherwise, no particular order for the eigenvalues is guaranteed.

Note: When eigenvalues are not explicitly defined, they are computed automatically from the matrix representation. Currently, this computation is *not* differentiable.

A `EigvalsUndefinedError` is raised if the eigenvalues have not been defined and cannot be inferred from the matrix representation.

See also:

`compute_eigvals()`

Returns
eigenvalues

Return type
tensor_like

expand()

Returns a tape that contains the decomposition of the operator.

Returns
quantum tape

Return type
.QuantumTape

generator()

Generator of an operator that is in single-parameter-form.

For example, for operator

$$U(\phi) = e^{i\phi(0.5Y + Z\otimes X)}$$

we get the generator

```
>>> U.generator()
  (0.5) [Y0]
+ (1.0) [Z0 X1]
```

The generator may also be provided in the form of a dense or sparse Hamiltonian (using `Hermitian` and `SparseHamiltonian` respectively).

The default value to return is `None`, indicating that the operation has no defined generator.

label(*decimals=None*, *base_label=None*, *cache=None*)

A customizable string representation of the operator.

Parameters

- **decimals=None** (*int*) – If None, no parameters are included. Else, specifies how to round the parameters.
- **base_label=None** (*str*) – overwrite the non-parameter component of the label
- **cache=None** (*dict*) – dictionary that carries information between label calls in the same drawing

Returns
label to use in drawings

Return type
str

Example:

```
>>> op = qml.RX(1.23456, wires=0)
>>> op.label()
"RX"
>>> op.label(base_label="my_label")
"my_label"
>>> op = qml.RX(1.23456, wires=0, id="test_data")
>>> op.label()
"RX("test_data")"
>>> op.label(decimals=2)
"RX\n(1.23,"test_data")"
>>> op.label(base_label="my_label")
"my_label("test_data")"
>>> op.label(decimals=2, base_label="my_label")
"my_label\n(1.23,"test_data")"
```

If the operation has a matrix-valued parameter and a cache dictionary is provided, unique matrices will be cached in the 'matrices' key list. The label will contain the index of the matrix in the 'matrices' list.

```
>>> op2 = qml.QubitUnitary(np.eye(2), wires=0)
>>> cache = {'matrices': []}
>>> op2.label(cache=cache)
'U(M0)'
>>> cache['matrices']
[tensor([[1., 0.],
 [0., 1.]], requires_grad=True)]
>>> op3 = qml.QubitUnitary(np.eye(4), wires=(0,1))
>>> op3.label(cache=cache)
'U(M1)'
>>> cache['matrices']
[tensor([[1., 0.],
        [0., 1.]], requires_grad=True),
tensor([[1., 0., 0., 0.],
        [0., 1., 0., 0.],
        [0., 0., 1., 0.],
        [0., 0., 0., 1.]], requires_grad=True)]
```

map_wires(*wire_map: dict*)

Returns a copy of the current operator with its wires changed according to the given wire map.

Parameters
wire_map (*dict*) – dictionary containing the old wires as keys and the new wires as values

Returns
new operator

Return type
.Operator

matrix(*wire_order=None*)

Representation of the operator as a matrix in the computational basis.

If `wire_order` is provided, the numerical representation considers the position of the operator's wires in the global wire order. Otherwise, the wire order defaults to the operator's wires.

If the matrix depends on trainable parameters, the result will be cast in the same autodifferentiation framework as the parameters.

A `MatrixUndefinedError` is raised if the matrix representation has not been defined.

See also:

`compute_matrix()`

Parameters
wire_order (*Iterable*) – global wire order, must contain all wire labels from the operator's wires

Returns
matrix representation

Return type
tensor_like

pow(*z*) → List[Operator]

A list of new operators equal to this one raised to the given power.

Parameters
z (*float*) – exponent for the operator

Returns
list[`Operator`]

queue(*context=<class 'pennylane.queuing.QueuingManager'>*)

Append the operator to the Operator queue.

simplify() → Operator

Reduce the depth of nested operators to the minimum.

Returns
simplified operator

Return type
.Operator

single_qubit_rot_angles()

The parameters required to implement a single-qubit gate as an equivalent `Rot` gate, up to a global phase.

Returns
A list of values $[\phi, \theta, \omega]$ such that $RZ(\omega)RY(\theta)RZ(\phi)$ is equivalent to the original operation.

Return type
tuple[float, float, float]

`sparse_matrix`(*wire_order=None*)

Representation of the operator as a sparse matrix in the computational basis.

If `wire_order` is provided, the numerical representation considers the position of the operator's wires in the global wire order. Otherwise, the wire order defaults to the operator's wires.

A `SparseMatrixUndefinedError` is raised if the sparse matrix representation has not been defined.

See also:

`compute_sparse_matrix()`

Parameters

wire_order (*Iterable*) – global wire order, must contain all wire labels from the operator's wires

Returns

sparse matrix representation

Return type

scipy.sparse._csr.csr_matrix

`terms`()

Representation of the operator as a linear combination of other operators.

$$O = \sum_i c_i O_i$$

A `TermsUndefinedError` is raised if no representation by terms is defined.

Returns

list of coefficients c_i and list of operations O_i

Return type

tuple[list[tensor_like or float], list[.Operation]]

`static validate_subspace`(*subspace*)

Validate the subspace for qutrit operations.

This method determines whether a given subspace for qutrit operations is defined correctly or not. If not, a *ValueError* is thrown.

Parameters

subspace (*tuple[int]*) – Subspace to check for correctness

BraketAwsAhsDevice

`class BraketAwsAhsDevice`(*wires: int | Iterable*, *device_arn: str*, *s3_destination_folder: S3DestinationFolder | None = None*, ***, *poll_timeout_seconds: float = 432000*, *poll_interval_seconds: float = 1*, *shots: int | Shots = Shots.DEFAULT*, *aws_session: AwsSession | None = None*)

Bases: `BraketAhsDevice`

Amazon Braket AHS device for hardware in PennyLane.

More information about AHS and the capabilities of the hardware can be found in the Amazon Braket Developer Guide.

Parameters

- **wires** (*int or Iterable[int, str]*) – Number of subsystems represented by the device, or iterable that contains unique labels for the subsystems as numbers (i.e., `[-1, 0, 2]`) or strings (`['ancilla', 'q1', 'q2']`).
- **device_arn** (*str*) – The ARN identifying the `AwsDevice` to be used to run circuits; The corresponding AwsDevice must support analog Hamiltonian simulation. You can get device ARNs from the Amazon Braket console or from the Amazon Braket Developer Guide.
- **s3_destination_folder** (*AwsSession.S3DestinationFolder*) – Name of the S3 bucket and folder, specified as a tuple.
- **poll_timeout_seconds** (*float*) – Total time in seconds to wait for results before timing out.
- **poll_interval_seconds** (*float*) – The polling interval for results in seconds.
- **shots** (*int or Shots.DEFAULT*) – Number of executions to run to aquire measurements. Default: Shots.DEFAULT
- **aws_session** (*Optional[AwsSession]*) – An AwsSession object created to manage interactions with AWS services, to be supplied if extra control is desired. Default: None

Note: It is important to keep track of units when specifying electromagnetic pulses for hardware control. The frequency and amplitude provided in PennyLane for Rydberg atom systems are expected to be in units of MHz, time in microseconds, phase in radians, and distance in micrometers. All of these will be converted to SI units internally as needed for upload to the hardware, and frequency will be converted to angular frequency (multiplied by 2π).

When reading hardware specifications from the Braket backend, bear in mind that all units are SI and frequencies are in rad/s. This conversion is done when creating a pulse program for upload, and units in the PennyLane functions should follow the conventions specified in the PennyLane docs to ensure correct unit conversion. See rydberg_interaction and rydberg_drive in Pennylane for specification of expected input units, and examples for creating hardware compatible ParametrizedEvolution operators in PennyLane.

ahs_program	
analytic	Whether shots is None or not.
author	
circuit_hash	The hash of the circuit upon the last execution.
hardware_capabilities	Dictionary of hardware capabilities for the hardware device
measurement_map	Mapping used to override the logic of measurement processes.
name	
num_executions	Number of times this device is executed by the evaluation of QNodes running on this device
obs_queue	The observables to be measured and returned.
observables	
op_queue	The operation queue to be applied.
operations	
parameters	Mapping from free parameter index to the list of `Operations` in the device queue that depend on it.
pennylane_requires	
register	Register a virtual subclass of an ABC.
result	
settings	Dictionary of constants set by the hardware.
short_name	
shot_vector	Returns the shot vector, a sparse representation of the shot sequence used by the device when evaluating QNodes.
shots	Number of circuit evaluations/random samples used to estimate expectation values of observables
state	Returns the state vector of the circuit prior to measurement.
stopping_condition	Returns the stopping condition for the device.
task	
version	
wire_map	Ordered dictionary that defines the map from user-provided wire labels to the wire labels used on this device
wires	All wires that can be addressed on this device

ahs_program

analytic

Whether shots is None or not. Kept for backwards compatability.

author = 'Xanadu Inc.'

circuit_hash

The hash of the circuit upon the last execution.

This can be used by devices in *apply()* for parametric compilation.

hardware_capabilities

Dictionary of hardware capabilities for the hardware device

measurement_map = {}

Mapping used to override the logic of measurement processes. The dictionary maps a measurement class to a string containing the name of a device's method that overrides the measurement process. The method defined by the device should have the following arguments:

- measurement (MeasurementProcess): measurement to override
- **shot_range (tuple[int]): 2-tuple of integers specifying the range of samples**
  to use. If not specified, all samples are used.
- **bin_size (int): Divides the shot range into bins of size `bin_size`, and**
  returns the measurement statistic separately over each bin. If not provided, the entire shot range is treated as a single bin.

Note: When overriding the logic of a `MeasurementTransform`, the method defined by the device should only have a single argument:

- tape: quantum tape to transform

Example:

Let's create a device that inherits from `DefaultQubitLegacy` and overrides the logic of the *qml.sample* measurement. To do so we will need to update the `measurement_map` dictionary:

```
class NewDevice(DefaultQubitLegacy):
    def __init__(self, wires, shots):
        super().__init__(wires=wires, shots=shots)
        self.measurement_map[SampleMP] = "sample_measurement"

    def sample_measurement(self, measurement, shot_range=None, bin_size=None):
        return 2
```

```
>>> dev = NewDevice(wires=2, shots=1000)
>>> @qml.qnode(dev)
... def circuit():
...     return qml.sample()
>>> circuit()
tensor(2, requires_grad=True)
```

name = 'Braket Device for AHS in PennyLane'

num_executions

Number of times this device is executed by the evaluation of QNodes running on this device

Returns
number of executions

Return type
int

obs_queue

The observables to be measured and returned.

Note that this property can only be accessed within the execution context of *execute()*.

Raises
`ValueError` – if outside of the execution context

Returns
list[~.operation.Observable]

observables = {'Hadamard', 'Hermitian', 'Identity', 'PauliX', 'PauliY', 'PauliZ', 'Prod', 'Projector', 'Sprod', 'Sum'}

op_queue

The operation queue to be applied.

Note that this property can only be accessed within the execution context of *execute()*.

Raises
`ValueError` – if outside of the execution context

Returns
list[~.operation.Operation]

operations = {'ParametrizedEvolution'}

parameters

Mapping from free parameter index to the list of `Operations` in the device queue that depend on it.

Note that this property can only be accessed within the execution context of *execute()*.

Raises
`ValueError` – if outside of the execution context

Returns
the mapping

Return type
dict[int->list[ParameterDependency]]

pennylane_requires = '>=0.30.0'

register

result

settings

Dictionary of constants set by the hardware.

Used to enable initializing hardware-consistent Hamiltonians by saving all the values that would need to be passed, i.e.:

```
>>> dev_remote = qml.device('braket.aws.ahs', wires=3)
>>> dev_pl = qml.device('default.qubit', wires=3)
>>> settings = dev_remote.settings
>>> H_int = qml.pulse.rydberg.rydberg_interaction(coordinates, **settings)
```

By passing the `settings` from the remote device to `rydberg_interaction`, an `H_int` Hamiltonian term is created using the constants specific to the hardware. This is relevant for simulating the hardware in PennyLane on the `default.qubit` device.

short_name = 'braket.aws.ahs'

shot_vector

Returns the shot vector, a sparse representation of the shot sequence used by the device when evaluating QNodes.

Example

```
>>> dev = qml.device("default.qubit.legacy", wires=2, shots=[3, 1, 2, 2, 2, 2,␣
↪6, 1, 1, 5, 12, 10, 10])
>>> dev.shots
57
>>> dev.shot_vector
[ShotCopies(3 shots x 1),
 ShotCopies(1 shots x 1),
 ShotCopies(2 shots x 4),
 ShotCopies(6 shots x 1),
 ShotCopies(1 shots x 2),
 ShotCopies(5 shots x 1),
 ShotCopies(12 shots x 1),
 ShotCopies(10 shots x 2)]
```

The sparse representation of the shot sequence is returned, where tuples indicate the number of times a shot integer is repeated.

Type

list[*ShotCopies*]

shots

Number of circuit evaluations/random samples used to estimate expectation values of observables

state

Returns the state vector of the circuit prior to measurement.

Note: Only state vector simulators support this property. Please see the plugin documentation for more details.

---

stopping_condition

Returns the stopping condition for the device. The returned function accepts a queuable object (including a PennyLane operation and observable) and returns `True` if supported by the device.

Type

.BooleanFn

task

version = '0.34.0'

wire_map

Ordered dictionary that defines the map from user-provided wire labels to the wire labels used on this device

wires

All wires that can be addressed on this device

access_state([wires])	Check that the device has access to an internal state and return it if available.
active_wires(operators)	Returns the wires acted on by a set of operators.
adjoint_jacobian(tape[, starting_state, ...])	Implements the adjoint method outlined in Jones and Gacon to differentiate an input tape.
analytic_probability([wires])	Return the (marginal) probability of each computational basis state from the last run of the device.
apply(operations, **kwargs)	Convert the pulse operation to an AHS program and run on the connected device
batch_execute(circuits)	Execute a batch of quantum circuits on the device.
batch_transform(circuit)	Apply a differentiable batch transform for preprocessing a circuit prior to execution.
capabilities()	Get the capabilities of this device class.
check_validity(queue, observables)	Checks whether the operations and observables in queue are all supported by the device.
classical_shadow(obs, circuit)	Returns the measured bits and recipes in the classical shadow protocol.
create_ahs_program(evolution)	Create AHS program for upload to hardware from a ParametrizedEvolution
custom_expand(fn)	Register a custom expansion function for the device.
default_expand_fn(circuit[, max_expansion])	Method for expanding or decomposing an input circuit.
define_wire_map(wires)	Create the map from user-provided wire labels to the wire labels used by the device.
density_matrix(wires)	Returns the reduced density matrix over the given wires.
estimate_probability([wires, shot_range, ...])	Return the estimated probability of each computational basis state using the generated samples.
execute(circuit, **kwargs)	It executes a queue of quantum operations on the device and then measure the given observables.
execute_and_gradients(circuits[, method])	Execute a batch of quantum circuits on the device, and return both the results and the gradients.
execution_context()	The device execution context used during calls to *execute()*.
expand_fn(circuit[, max_expansion])	Method for expanding or decomposing an input circuit.
expval(observable[, shot_range, bin_size])	Returns the expectation value of observable on specified wires.
generate_basis_states(num_wires[, dtype])	Generates basis states in binary representation according to the number of wires specified.
generate_samples()	Returns the computational basis samples measured for all wires.
gradients(circuits[, method])	Return the gradients of a batch of quantum circuits on the device.
map_wires(wires)	Map the wire labels of wires using this device's wire map.
marginal_prob(prob[, wires])	Return the marginal probability of the computational basis states by summing the probabiliites on the non-specified wires.
mutual_info(wires0, wires1, log_base)	Returns the mutual information prior to measurement:

continues on next page

Table 1 – continued from previous page

order_wires(subset_wires)	Given some subset of device wires return a Wires object with the same wires; sorted according to the device wire map.
post_apply()	Called during *execute()* after the individual operations have been executed.
post_measure()	Called during *execute()* after the individual observables have been measured.
pre_apply()	Called during *execute()* before the individual operations are executed.
pre_measure()	Called during *execute()* before the individual observables are measured.
probability([wires, shot_range, bin_size])	Return either the analytic probability or estimated probability of each computational basis state.
reset()	Reset the backend state.
sample(observable[, shot_range, bin_size, ...])	Return samples of an observable.
sample_basis_states(number_of_states, ...)	Sample from the computational basis states based on the state probability.
shadow_expval(obs, circuit)	Compute expectation values using classical shadows in a differentiable manner.
shot_vec_statistics(circuit)	Process measurement results from circuit execution using a device with a shot vector and return statistics.
states_to_binary(samples, num_wires[, dtype])	Convert basis states from base 10 to binary representation.
statistics(circuit[, shot_range, bin_size])	Process measurement results from circuit execution and return statistics.
supports_observable(observable)	Checks if an observable is supported by this device. Raises a ValueError,
supports_operation(operation)	Checks if an operation is supported by this device.
var(observable[, shot_range, bin_size])	Returns the variance of observable on specified wires.
vn_entropy(wires, log_base)	Returns the Von Neumann entropy prior to measurement.

access_state(*wires=None*)

Check that the device has access to an internal state and return it if available.

Parameters
: **wires** (*Wires*) – wires of the reduced system

Raises
: **QuantumFunctionError** – if the device is not capable of returning the state

Returns
: the state or the density matrix of the device

Return type
: array or tensor

static active_wires(*operators*)

Returns the wires acted on by a set of operators.

Parameters
: **operators** (*list[Operation]*) – operators for which we are gathering the active wires

Returns
: wires activated by the specified operators

Return type
Wires

`adjoint_jacobian`(*tape: QuantumTape*, *starting_state=None*, *use_device_state=False*)

Implements the adjoint method outlined in Jones and Gacon to differentiate an input tape.

After a forward pass, the circuit is reversed by iteratively applying adjoint gates to scan backwards through the circuit.

Note: The adjoint differentiation method has the following restrictions:

- As it requires knowledge of the statevector, only statevector simulator devices can be used.
- Only expectation values are supported as measurements.
- Does not work for parametrized observables like `Hamiltonian` or `Hermitian`.

Parameters
tape (*.QuantumTape*) – circuit that the function takes the gradient of

Keyword Arguments

- **starting_state** (*tensor_like*) – post-forward pass state to start execution with. It should be complex-valued. Takes precedence over `use_device_state`.
- **use_device_state** (*bool*) – use current device state to initialize. A forward pass of the same circuit should be the last thing the device has executed. If a `starting_state` is provided, that takes precedence.

Returns
the derivative of the tape with respect to trainable parameters. Dimensions are `(len(observables), len(trainable_params))`.

Return type
array or tuple[array]

Raises
QuantumFunctionError – if the input tape has measurements that are not expectation values or contains a multi-parameter operation aside from `Rot`

`analytic_probability`(*wires=None*)

Return the (marginal) probability of each computational basis state from the last run of the device.

PennyLane uses the convention $|q_0, q_1, \dots, q_{N-1}\rangle$ where q_0 is the most significant bit.

If no wires are specified, then all the basis states representable by the device are considered and no marginalization takes place.

Note: *marginal_prob()* may be used as a utility method to calculate the marginal probability distribution.

Parameters
wires (*Iterable[Number, str], Number, str, Wires*) – wires to return marginal probabilities for. Wires not provided are traced out of the system.

Returns
list of the probabilities

Return type
array[float]

`apply`(*operations: list[ParametrizedEvolution]*, ***kwargs*)

Convert the pulse operation to an AHS program and run on the connected device

Parameters
operations (*list[ParametrizedEvolution]*) – a list containing a single ParametrizedEvolution operator

`batch_execute`(*circuits*)

Execute a batch of quantum circuits on the device.

The circuits are represented by tapes, and they are executed one-by-one using the device's `execute` method. The results are collected in a list.

For plugin developers: This function should be overwritten if the device can efficiently run multiple circuits on a backend, for example using parallel and/or asynchronous executions.

Parameters
circuits (*list[QuantumTape]*) – circuits to execute on the device

Returns
list of measured value(s)

Return type
list[array[float]]

`batch_transform`(*circuit: QuantumTape*)

Apply a differentiable batch transform for preprocessing a circuit prior to execution. This method is called directly by the QNode, and should be overwritten if the device requires a transform that generates multiple circuits prior to execution.

By default, this method contains logic for generating multiple circuits, one per term, of a circuit that terminates in `expval(H)`, if the underlying device does not support Hamiltonian expectation values, or if the device requires finite shots.

> **Warning:** This method will be tracked by autodifferentiation libraries, such as Autograd, JAX, TensorFlow, and Torch. Please make sure to use `qml.math` for autodiff-agnostic tensor processing if required.

Parameters
circuit (*.QuantumTape*) – the circuit to preprocess

Returns
Returns a tuple containing the sequence of circuits to be executed, and a post-processing function to be applied to the list of evaluated circuit results.

Return type
tuple[Sequence[.QuantumTape], callable]

`classmethod capabilities`()

Get the capabilities of this device class.

Inheriting classes that change or add capabilities must override this method, for example via

```
@classmethod
def capabilities(cls):
    capabilities = super().capabilities().copy()
    capabilities.update(
        supports_a_new_capability=True,
    )
    return capabilities
```

Returns
results

Return type
dict[str->*]

check_validity(*queue*, *observables*)

Checks whether the operations and observables in queue are all supported by the device.

Parameters

- **queue** (*Iterable[Operation]*) – quantum operation objects which are intended to be applied on the device
- **observables** (*Iterable[Observable]*) – observables which are intended to be evaluated on the device

Raises
Exception – if there are operations in the queue or observables that the device does not support

classical_shadow(*obs*, *circuit*)

Returns the measured bits and recipes in the classical shadow protocol.

The protocol is described in detail in the classical shadows paper. This measurement process returns the randomized Pauli measurements (the `recipes`) that are performed for each qubit and snapshot as an integer:

- 0 for Pauli X,
- 1 for Pauli Y, and
- 2 for Pauli Z.

It also returns the measurement results (the `bits`); 0 if the 1 eigenvalue is sampled, and 1 if the -1 eigenvalue is sampled.

The device shots are used to specify the number of snapshots. If `T` is the number of shots and `n` is the number of qubits, then both the measured bits and the Pauli measurements have shape `(T, n)`.

This implementation is device-agnostic and works by executing single-shot tapes containing randomized Pauli observables. Devices should override this if they can offer cleaner or faster implementations.

See also:

`classical_shadow()`

Parameters

- **obs** (*ClassicalShadowMP*) – The classical shadow measurement process
- **circuit** (*QuantumTape*) – The quantum tape that is being executed

Returns
A tensor with shape `(2, T, n)`, where the first row represents the measured bits and the second represents the recipes used.

Return type
tensor_like[int]

create_ahs_program(*evolution: ParametrizedEvolution*)

Create AHS program for upload to hardware from a ParametrizedEvolution

Parameters
evolution (*ParametrizedEvolution*) – the PennyLane operator describing the pulse to be converted into an AnalogHamiltonianSimulation program

Returns

a program containing the register and drive
information for running an AHS task on simulation or hardware

Return type
AnalogHamiltonianSimulation

custom_expand(*fn*)

Register a custom expansion function for the device.

Example

```
dev = qml.device("default.qubit.legacy", wires=2)

@dev.custom_expand
def my_expansion_function(self, tape, max_expansion=10):
    ...
    # can optionally call the default device expansion
    tape = self.default_expand_fn(tape, max_expansion=max_expansion)
    return tape
```

The custom device expansion function must have arguments `self` (the device object), `tape` (the input circuit to transform and execute), and `max_expansion` (the number of times the circuit should be expanded).

The default *default_expand_fn()* method of the original device may be called. It is highly recommended to call this before returning, to ensure that the expanded circuit is supported on the device.

default_expand_fn(*circuit*, *max_expansion=10*)

Method for expanding or decomposing an input circuit. This method should be overwritten if custom expansion logic is required.

By default, this method expands the tape if:

- state preparation operations are called mid-circuit,
- nested tapes are present,
- any operations are not supported on the device, or
- multiple observables are measured on the same wire.

Parameters

- **circuit** (*.QuantumTape*) – the circuit to expand.

- **max_expansion** (*int*) – The number of times the circuit should be expanded. Expansion occurs when an operation or measurement is not supported, and results in a gate decomposition. If any operations in the decomposition remain unsupported by the device, another expansion occurs.

Returns
The expanded/decomposed circuit, such that the device will natively support all operations.

Return type
.QuantumTape

define_wire_map(*wires*)

Create the map from user-provided wire labels to the wire labels used by the device.

The default wire map maps the user wire labels to wire labels that are consecutive integers.

However, by overwriting this function, devices can specify their preferred, non-consecutive and/or non-integer wire labels.

Parameters
wires (*Wires*) – user-provided wires for this device

Returns
dictionary specifying the wire map

Return type
OrderedDict

Example

```
>>> dev = device('my.device', wires=['b', 'a'])
>>> dev.wire_map()
OrderedDict( [(<Wires = ['a']>, <Wires = [0]>), (<Wires = ['b']>, <Wires = [1]>
↪)])
```

density_matrix(*wires*)

Returns the reduced density matrix over the given wires.

Parameters
wires (*Wires*) – wires of the reduced system

Returns
complex array of shape `(2 ** len(wires), 2 ** len(wires))` representing the reduced density matrix of the state prior to measurement.

Return type
array[complex]

estimate_probability(*wires=None*, *shot_range=None*, *bin_size=None*)

Return the estimated probability of each computational basis state using the generated samples.

Parameters

- **wires** (*Iterable[Number, str], Number, str, Wires*) – wires to calculate marginal probabilities for. Wires not provided are traced out of the system.
- **shot_range** (*tuple[int]*) – 2-tuple of integers specifying the range of samples to use. If not specified, all samples are used.
- **bin_size** (*int*) – Divides the shot range into bins of size `bin_size`, and returns the measurement statistic separately over each bin. If not provided, the entire shot range is treated as a single bin.

Returns
list of the probabilities

Return type
array[float]

execute(*circuit*, ***kwargs*)

It executes a queue of quantum operations on the device and then measure the given observables.

For plugin developers: instead of overwriting this, consider implementing a suitable subset of

- *apply()*
- *generate_samples()*
- *probability()*

Additional keyword arguments may be passed to this method that can be utilised by *apply()*. An example would be passing the `QNode` hash that can be used later for parametric compilation.

Parameters
circuit (*QuantumTape*) – circuit to execute on the device

Raises
QuantumFunctionError – if the value of `return_type` is not supported

Returns
measured value(s)

Return type
array[float]

execute_and_gradients(*circuits*, *method='jacobian'*, ***kwargs*)

Execute a batch of quantum circuits on the device, and return both the results and the gradients.

The circuits are represented by tapes, and they are executed one-by-one using the device's `execute` method. The results and the corresponding Jacobians are collected in a list.

For plugin developers: This method should be overwritten if the device can efficiently run multiple circuits on a backend, for example using parallel and/or asynchronous executions, and return both the results and the Jacobians.

Parameters

- **circuits** (*list[.tape.QuantumTape]*) – circuits to execute on the device
- **method** (*str*) – the device method to call to compute the Jacobian of a single circuit
- ****kwargs** – keyword argument to pass when calling `method`

Returns
Tuple containing list of measured value(s) and list of Jacobians. Returned Jacobians should be of shape `(output_shape, num_params)`.

Return type
tuple[list[array[float]], list[array[float]]]

execution_context()

The device execution context used during calls to *execute()*.

You can overwrite this function to return a context manager in case your quantum library requires that; all operations and method calls (including *apply()* and *expval()*) are then evaluated within the context of this context manager (see the source of *execute()* for more details).

expand_fn(*circuit*, *max_expansion=10*)

Method for expanding or decomposing an input circuit. Can be the default or a custom expansion method, see `Device.default_expand_fn()` and `Device.custom_expand()` for more details.

Parameters

- **circuit** (*.QuantumTape*) – the circuit to expand.
- **max_expansion** (*int*) – The number of times the circuit should be expanded. Expansion occurs when an operation or measurement is not supported, and results in a gate decomposition. If any operations in the decomposition remain unsupported by the device, another expansion occurs.

Returns

The expanded/decomposed circuit, such that the device will natively support all operations.

Return type

.QuantumTape

expval(*observable*, *shot_range=None*, *bin_size=None*)

Returns the expectation value of observable on specified wires.

Note: all arguments accept _lists_, which indicate a tensor product of observables.

Parameters

- **observable** (*str or list[str]*) – name of the observable(s)
- **wires** (*Wires*) – wires the observable(s) are to be measured on
- **par** (*tuple or list[tuple]]*) – parameters for the observable(s)

Returns

expectation value $A = \psi A \psi$

Return type

float

static generate_basis_states(*num_wires*, *dtype=<class 'numpy.uint32'>*)

Generates basis states in binary representation according to the number of wires specified.

The states_to_binary method creates basis states faster (for larger systems at times over x25 times faster) than the approach using `itertools.product`, at the expense of using slightly more memory.

Due to the large size of the integer arrays for more than 32 bits, memory allocation errors may arise in the states_to_binary method. Hence we constraint the dtype of the array to represent unsigned integers on 32 bits. Due to this constraint, an overflow occurs for 32 or more wires, therefore this approach is used only for fewer wires.

For smaller number of wires speed is comparable to the next approach (using `itertools.product`), hence we resort to that one for testing purposes.

Parameters

- **num_wires** (*int*) – the number wires
- **dtype=np.uint32** (*type*) – the data type of the arrays to use

Returns

the sampled basis states

Return type

array[int]

generate_samples()

Returns the computational basis samples measured for all wires.

Returns
array of samples in the shape `(dev.shots, dev.num_wires)`

Return type
array[complex]

gradients(*circuits*, *method='jacobian'*, ***kwargs*)

Return the gradients of a batch of quantum circuits on the device.

The gradient method `method` is called sequentially for each circuit, and the corresponding Jacobians are collected in a list.

For plugin developers: This method should be overwritten if the device can efficiently compute the gradient of multiple circuits on a backend, for example using parallel and/or asynchronous executions.

Parameters

- **circuits** (*list[.tape.QuantumTape]*) – circuits to execute on the device
- **method** (*str*) – the device method to call to compute the Jacobian of a single circuit
- ****kwargs** – keyword argument to pass when calling `method`

Returns
List of Jacobians. Returned Jacobians should be of shape `(output_shape, num_params)`.

Return type
list[array[float]]

map_wires(*wires*)

Map the wire labels of wires using this device's wire map.

Parameters
wires (*Wires*) – wires whose labels we want to map to the device's internal labelling scheme

Returns
wires with new labels

Return type
Wires

marginal_prob(*prob*, *wires=None*)

Return the marginal probability of the computational basis states by summing the probabiliites on the non-specified wires.

If no wires are specified, then all the basis states representable by the device are considered and no marginalization takes place.

Note: If the provided wires are not in the order as they appear on the device, the returned marginal probabilities take this permutation into account.

For example, if the addressable wires on this device are `Wires([0, 1, 2])` and this function gets passed `wires=[2, 0]`, then the returned marginal probability vector will take this 'reversal' of the two wires into account:

$$\mathbb{P}^{(2,0)} = [|00\rangle, |10\rangle, |01\rangle, |11\rangle]$$

Parameters

- **prob** – The probabilities to return the marginal probabilities for
- **wires** (*Iterable[Number, str], Number, str, Wires*) – wires to return marginal probabilities for. Wires not provided are traced out of the system.

Returns
array of the resulting marginal probabilities.

Return type
array[float]

mutual_info(*wires0*, *wires1*, *log_base*)

Returns the mutual information prior to measurement:

$$I(A,B) = S(\rho^A) + S(\rho^B) - S(\rho^{AB})$$

where S is the von Neumann entropy.

Parameters

- **wires0** (*Wires*) – wires of the first subsystem
- **wires1** (*Wires*) – wires of the second subsystem
- **log_base** (*float*) – base to use in the logarithm

Returns
the mutual information

Return type
float

order_wires(*subset_wires*)

Given some subset of device wires return a Wires object with the same wires; sorted according to the device wire map.

Parameters
subset_wires (*Wires*) – The subset of device wires (in any order).

Raises
ValueError – Could not find some or all subset wires subset_wires in device wires device_wires.

Returns
a new Wires object containing the re-ordered wires set

Return type
ordered_wires (Wires)

post_apply()

Called during *execute()* after the individual operations have been executed.

post_measure()

Called during *execute()* after the individual observables have been measured.

pre_apply()

Called during *execute()* before the individual operations are executed.

pre_measure()

Called during *execute()* before the individual observables are measured.

`probability`(*wires=None*, *shot_range=None*, *bin_size=None*)

Return either the analytic probability or estimated probability of each computational basis state.

Devices that require a finite number of shots always return the estimated probability.

Parameters

`wires` (*Iterable[Number, str], Number, str, Wires*) – wires to return marginal probabilities for. Wires not provided are traced out of the system.

Returns

list of the probabilities

Return type

array[float]

`reset`()

Reset the backend state.

After the reset, the backend should be as if it was just constructed. Most importantly the quantum state is reset to its initial value.

`sample`(*observable*, *shot_range=None*, *bin_size=None*, *counts=False*)

Return samples of an observable.

Parameters

- `observable` (*Observable*) – the observable to sample
- `shot_range` (*tuple[int]*) – 2-tuple of integers specifying the range of samples to use. If not specified, all samples are used.
- `bin_size` (*int*) – Divides the shot range into bins of size `bin_size`, and returns the measurement statistic separately over each bin. If not provided, the entire shot range is treated as a single bin.
- `counts` (*bool*) – whether counts (`True`) or raw samples (`False`) should be returned

Raises

`EigvalsUndefinedError` – if no information is available about the eigenvalues of the observable

Returns

samples in an array of dimension `(shots,)` or counts

Return type

Union[array[float], dict, list[dict]]

`sample_basis_states`(*number_of_states*, *state_probability*)

Sample from the computational basis states based on the state probability.

This is an auxiliary method to the generate_samples method.

Parameters

- `number_of_states` (*int*) – the number of basis states to sample from
- `state_probability` (*array[float]*) – the computational basis probability vector

Returns

the sampled basis states

Return type

array[int]

shadow_expval(*obs*, *circuit*)

Compute expectation values using classical shadows in a differentiable manner.

Please refer to `shadow_expval()` for detailed documentation.

Parameters

- **obs** (*ClassicalShadowMP*) – The classical shadow expectation value measurement process
- **circuit** (*QuantumTape*) – The quantum tape that is being executed

Returns
expectation value estimate.

Return type
float

shot_vec_statistics(*circuit: QuantumTape*)

Process measurement results from circuit execution using a device with a shot vector and return statistics.

This is an auxiliary method of execute and uses statistics.

When using shot vectors, measurement results for each item of the shot vector are contained in a tuple.

Parameters
circuit (*QuantumTape*) – circuit to execute on the device

Raises
QuantumFunctionError – if the value of `return_type` is not supported

Returns
stastics for each shot item from the shot vector

Return type
tuple

static states_to_binary(*samples*, *num_wires*, *dtype=<class 'numpy.int64'>*)

Convert basis states from base 10 to binary representation.

This is an auxiliary method to the generate_samples method.

Parameters

- **samples** (*array[int]*) – samples of basis states in base 10 representation
- **num_wires** (*int*) – the number of qubits
- **dtype** (*type*) – Type of the internal integer array to be used. Can be important to specify for large systems for memory allocation purposes.

Returns
basis states in binary representation

Return type
array[int]

statistics(*circuit: QuantumTape*, *shot_range=None*, *bin_size=None*)

Process measurement results from circuit execution and return statistics.

This includes returning expectation values, variance, samples, probabilities, states, and density matrices.

Parameters

- **circuit** (*QuantumTape*) – the quantum tape currently being executed

- **shot_range** (*tuple[int]*) – 2-tuple of integers specifying the range of samples to use. If not specified, all samples are used.
- **bin_size** (*int*) – Divides the shot range into bins of size `bin_size`, and returns the measurement statistic separately over each bin. If not provided, the entire shot range is treated as a single bin.

Raises
`QuantumFunctionError` – if the value of `return_type` is not supported

Returns
the corresponding statistics

Return type
Union[float, List[float]]

`supports_observable`(*observable*)

Checks if an observable is supported by this device. Raises a ValueError,
if not a subclass or string of an Observable was passed.

Parameters
observable (*type or str*) – observable to be checked

Raises
`ValueError` – if *observable* is not a `Observable` class or string

Returns
`True` iff supplied observable is supported

Return type
bool

`supports_operation`(*operation*)

Checks if an operation is supported by this device.

Parameters
operation (*type or str*) – operation to be checked

Raises
`ValueError` – if *operation* is not a `Operation` class or string

Returns
`True` if supplied operation is supported

Return type
bool

`var`(*observable*, *shot_range=None*, *bin_size=None*)

Returns the variance of observable on specified wires.

Note: all arguments support _lists_, which indicate a tensor product of observables.

Parameters

- **observable** (*str or list[str]*) – name of the observable(s)
- **wires** (*Wires*) – wires the observable(s) is to be measured on
- **par** (*tuple or list[tuple]]*) – parameters for the observable(s)

Raises
`NotImplementedError` – if the device does not support variance computation

Returns
variance $\mathrm{var}(A) = \psi A^2 \psi - \psi A \psi^2$

Return type
float

`vn_entropy`(*wires*, *log_base*)

Returns the Von Neumann entropy prior to measurement.

$$S(\rho) = -\mathrm{Tr}(\rho \log(\rho))$$

Parameters

- **wires** (*Wires*) – Wires of the considered subsystem.
- **log_base** (*float*) – Base for the logarithm, default is None the natural logarithm is used in this case.

Returns
returns the Von Neumann entropy

Return type
float

BraketAwsQubitDevice

`class BraketAwsQubitDevice`(*wires: int | Iterable*, *device_arn: str*, *s3_destination_folder: S3DestinationFolder | None = None*, ***, *shots: int | None | Shots = Shots.DEFAULT*, *poll_timeout_seconds: float = 432000*, *poll_interval_seconds: float = 1*, *aws_session: AwsSession | None = None*, *parallel: bool = False*, *max_parallel: int | None = None*, *max_connections: int = 100*, *max_retries: int = 3*, ***run_kwargs*)

Bases: `BraketQubitDevice`

Amazon Braket AwsDevice qubit device for PennyLane.

Parameters

- **wires** (*int or Iterable[Number, str]]*) – Number of subsystems represented by the device, or iterable that contains unique labels for the subsystems as numbers (i.e., `[-1, 0, 2]`) or strings (`['ancilla', 'q1', 'q2']`).
- **device_arn** (*str*) – The ARN identifying the `AwsDevice` to be used to run circuits; The corresponding AwsDevice must support quantum circuits via OpenQASM. You can get device ARNs using `AwsDevice.get_devices`, from the Amazon Braket console or from the Amazon Braket Developer Guide.
- **s3_destination_folder** (*AwsSession.S3DestinationFolder*) – Name of the S3 bucket and folder, specified as a tuple.
- **poll_timeout_seconds** (*float*) – Total time in seconds to wait for results before timing out.
- **poll_interval_seconds** (*float*) – The polling interval for results in seconds.
- **shots** (*int, None or Shots.DEFAULT*) – Number of circuit evaluations or random samples included, to estimate expectation values of observables. If set to Shots.DEFAULT, uses the default number of shots specified by the remote device. If `shots` is set to `0` or `None`, the device runs in analytic mode (calculations will be exact). Analytic mode is not available on QPU and hence an error will be raised. Default: Shots.DEFAULT

- **aws_session** (*Optional[AwsSession]*) – An AwsSession object created to manage interactions with AWS services, to be supplied if extra control is desired. Default: None Default: False
- **max_parallel** (*int, optional*) – Maximum number of tasks to run on AWS in parallel. Batch creation will fail if this value is greater than the maximum allowed concurrent tasks on the device. If unspecified, uses defaults defined in `AwsDevice`. Ignored if `parallel=False`.
- **max_connections** (*int*) – The maximum number of connections in the Boto3 connection pool. Also the maximum number of thread pool workers for the batch. Ignored if `parallel=False`.
- **max_retries** (*int*) – The maximum number of retries to use for batch execution. When executing tasks in parallel, failed tasks will be retried up to `max_retries` times. Ignored if `parallel=False`.
- **verbatim** (*bool*) – Whether to verbatim mode for the device. Note that verbatim mode only supports the native gate set of the device. Default False.
- ****run_kwargs** – Variable length keyword arguments for `braket.devices.Device.run()`.

analytic	Whether shots is None or not.
author	
circuit	The last circuit run on this device.
circuit_hash	The hash of the circuit upon the last execution.
measurement_map	Mapping used to override the logic of measurement processes.
name	
num_executions	Number of times this device is executed by the evaluation of QNodes running on this device
obs_queue	The observables to be measured and returned.
observables	set() -> new empty set object set(iterable) -> new set object
op_queue	The operation queue to be applied.
operations	The set of names of PennyLane operations that the device supports.
parallel	
parameters	Mapping from free parameter index to the list of `Operations` in the device queue that depend on it.
pennylane_requires	
pulse_settings	Dictionary of constants set by the hardware (qubit resonant frequencies, inter-qubit connection graph, wires and anharmonicities).
short_name	
shot_vector	Returns the shot vector, a sparse representation of the shot sequence used by the device when evaluating QNodes.
shots	Number of circuit evaluations/random samples used to estimate expectation values of observables
state	Returns the state vector of the circuit prior to measurement.
stopping_condition	Returns the stopping condition for the device.
task	The task corresponding to the last run circuit.
use_grouping	
version	
wire_map	Ordered dictionary that defines the map from user-provided wire labels to the wire labels used on this device
wires	All wires that can be addressed on this device

analytic

Whether shots is None or not. Kept for backwards compatability.

author = 'Amazon Web Services'

circuit

The last circuit run on this device.

Type
Circuit

circuit_hash

The hash of the circuit upon the last execution.

This can be used by devices in *apply()* for parametric compilation.

measurement_map = {}

Mapping used to override the logic of measurement processes. The dictionary maps a measurement class to a string containing the name of a device's method that overrides the measurement process. The method defined by the device should have the following arguments:

- measurement (MeasurementProcess): measurement to override
- **shot_range (tuple[int]): 2-tuple of integers specifying the range of samples**
  to use. If not specified, all samples are used.
- **bin_size (int): Divides the shot range into bins of size `bin_size`, and**
  returns the measurement statistic separately over each bin. If not provided, the entire shot range is treated as a single bin.

Note: When overriding the logic of a `MeasurementTransform`, the method defined by the device should only have a single argument:

- tape: quantum tape to transform

Example:

Let's create a device that inherits from `DefaultQubitLegacy` and overrides the logic of the *qml.sample* measurement. To do so we will need to update the `measurement_map` dictionary:

```
class NewDevice(DefaultQubitLegacy):
    def __init__(self, wires, shots):
        super().__init__(wires=wires, shots=shots)
        self.measurement_map[SampleMP] = "sample_measurement"

    def sample_measurement(self, measurement, shot_range=None, bin_size=None):
        return 2
```

```
>>> dev = NewDevice(wires=2, shots=1000)
>>> @qml.qnode(dev)
... def circuit():
...     return qml.sample()
>>> circuit()
tensor(2, requires_grad=True)
```

name = 'Braket AwsDevice for PennyLane'

num_executions

Number of times this device is executed by the evaluation of QNodes running on this device

Returns
number of executions

Return type
int

obs_queue

The observables to be measured and returned.

Note that this property can only be accessed within the execution context of *execute()*.

Raises
`ValueError` – if outside of the execution context

Returns
list[~.operation.Observable]

observables

op_queue

The operation queue to be applied.

Note that this property can only be accessed within the execution context of *execute()*.

Raises
`ValueError` – if outside of the execution context

Returns
list[~.operation.Operation]

operations

The set of names of PennyLane operations that the device supports.

Type
frozenset[str]

parallel

parameters

Mapping from free parameter index to the list of `Operations` in the device queue that depend on it.

Note that this property can only be accessed within the execution context of *execute()*.

Raises
`ValueError` – if outside of the execution context

Returns
the mapping

Return type
dict[int->list[ParameterDependency]]

pennylane_requires = '>=0.30.0'

pulse_settings

Dictionary of constants set by the hardware (qubit resonant frequencies, inter-qubit connection graph, wires and anharmonicities).

Used to enable initializing hardware-consistent Hamiltonians by returning values that would need to be passed, i.e.:

```
>>> dev_remote = qml.device('braket.aws.qubit',
>>>                          wires=8,
>>>                          arn='arn:aws:braket:eu-west-2::device/qpu/oqc/Lucy
↪')
>>> pulse_settings = dev_remote.pulse_settings
>>> H_int = qml.pulse.transmon_interaction(**pulse_settings, coupling=0.02)
```

By passing the `pulse_settings` from the remote device to `transmon_interaction`, an `H_int` Hamiltonian term is created using the constants specific to the hardware. This is relevant for simulating the hardware in PennyLane on the `default.qubit` device.

Note that the user must supply coupling coefficients, as these are not available from the hardware backend.

short_name = 'braket.aws.qubit'

shot_vector

Returns the shot vector, a sparse representation of the shot sequence used by the device when evaluating QNodes.

Example

```
>>> dev = qml.device("default.qubit.legacy", wires=2, shots=[3, 1, 2, 2, 2, 2,␣
↪6, 1, 1, 5, 12, 10, 10])
>>> dev.shots
57
>>> dev.shot_vector
[ShotCopies(3 shots x 1),
 ShotCopies(1 shots x 1),
 ShotCopies(2 shots x 4),
 ShotCopies(6 shots x 1),
 ShotCopies(1 shots x 2),
 ShotCopies(5 shots x 1),
 ShotCopies(12 shots x 1),
 ShotCopies(10 shots x 2)]
```

The sparse representation of the shot sequence is returned, where tuples indicate the number of times a shot integer is repeated.

Type
list[*ShotCopies*]

shots

Number of circuit evaluations/random samples used to estimate expectation values of observables

state

Returns the state vector of the circuit prior to measurement.

Note: Only state vector simulators support this property. Please see the plugin documentation for more details.

stopping_condition

Returns the stopping condition for the device. The returned function accepts a queuable object (including a PennyLane operation and observable) and returns `True` if supported by the device.

Type
.BooleanFn

task

The task corresponding to the last run circuit.

Type
QuantumTask

`use_grouping`

`version = '1.24.2'`

`wire_map`

Ordered dictionary that defines the map from user-provided wire labels to the wire labels used on this device

`wires`

All wires that can be addressed on this device

access_state([wires])	Check that the device has access to an internal state and return it if available.
active_wires(operators)	Returns the wires acted on by a set of operators.
adjoint_jacobian(tape[, starting_state, ...])	Implements the adjoint method outlined in Jones and Gacon to differentiate an input tape.
analytic_probability([wires])	Return the (marginal) probability of each computational basis state from the last run of the device.
apply(operations[, rotations, ...])	Instantiate Braket Circuit object.
batch_execute(circuits, **run_kwargs)	Execute a batch of quantum circuits on the device.
batch_transform(circuit)	Apply a differentiable batch transform for preprocessing a circuit prior to execution.
capabilities()	Add support for AG on sv1
check_validity(queue, observables)	Check validity of pulse operations before running the standard check_validity function
classical_shadow(obs, circuit)	Returns the measured bits and recipes in the classical shadow protocol.
custom_expand(fn)	Register a custom expansion function for the device.
default_expand_fn(circuit[, max_expansion])	Method for expanding or decomposing an input circuit.
define_wire_map(wires)	Create the map from user-provided wire labels to the wire labels used by the device.
density_matrix(wires)	Returns the reduced density matrix over the given wires.
estimate_probability([wires, shot_range, ...])	Return the estimated probability of each computational basis state using the generated samples.
execute(circuit[, compute_gradient])	It executes a queue of quantum operations on the device and then measure the given observables.
execute_and_gradients(circuits, **kwargs)	Execute a list of circuits and calculate their gradients.
execution_context()	The device execution context used during calls to *execute()*.
expand_fn(circuit[, max_expansion])	Method for expanding or decomposing an input circuit.
expval(observable[, shot_range, bin_size])	Returns the expectation value of observable on specified wires.
generate_basis_states(num_wires[, dtype])	Generates basis states in binary representation according to the number of wires specified.
generate_samples()	Returns the computational basis samples generated for all wires.
gradients(circuits[, method])	Return the gradients of a batch of quantum circuits on the device.
map_wires(wires)	Map the wire labels of wires using this device's wire map.

continues on next page

Table 2 – continued from previous page

marginal_prob(prob[, wires])	Return the marginal probability of the computational basis states by summing the probabiliites on the non-specified wires.
mutual_info(wires0, wires1, log_base)	Returns the mutual information prior to measurement:
order_wires(subset_wires)	Given some subset of device wires return a Wires object with the same wires; sorted according to the device wire map.
post_apply()	Called during *execute()* after the individual operations have been executed.
post_measure()	Called during *execute()* after the individual observables have been measured.
pre_apply()	Called during *execute()* before the individual operations are executed.
pre_measure()	Called during *execute()* before the individual observables are measured.
probability([wires, shot_range, bin_size])	Return either the analytic probability or estimated probability of each computational basis state.
reset()	Reset the backend state.
sample(observable[, shot_range, bin_size, ...])	Return samples of an observable.
sample_basis_states(number_of_states, ...)	Sample from the computational basis states based on the state probability.
shadow_expval(obs, circuit)	Compute expectation values using classical shadows in a differentiable manner.
shot_vec_statistics(circuit)	Process measurement results from circuit execution using a device with a shot vector and return statistics.
states_to_binary(samples, num_wires[, dtype])	Convert basis states from base 10 to binary representation.
statistics(braket_result, measurements)	Processes measurement results from a Braket task result and returns statistics.
supports_observable(observable)	Checks if an observable is supported by this device. Raises a ValueError,
supports_operation(operation)	Checks if an operation is supported by this device.
var(observable[, shot_range, bin_size])	Returns the variance of observable on specified wires.
vn_entropy(wires, log_base)	Returns the Von Neumann entropy prior to measurement.

access_state(*wires=None*)

Check that the device has access to an internal state and return it if available.

Parameters

wires (*Wires*) – wires of the reduced system

Raises

QuantumFunctionError – if the device is not capable of returning the state

Returns

the state or the density matrix of the device

Return type

array or tensor

static active_wires(*operators*)

Returns the wires acted on by a set of operators.

Parameters
`operators` (*list[Operation]*) – operators for which we are gathering the active wires

Returns
wires activated by the specified operators

Return type
Wires

`adjoint_jacobian`(*tape: QuantumTape*, *starting_state=None*, *use_device_state=False*)

Implements the adjoint method outlined in Jones and Gacon to differentiate an input tape.

After a forward pass, the circuit is reversed by iteratively applying adjoint gates to scan backwards through the circuit.

Note: The adjoint differentiation method has the following restrictions:

- As it requires knowledge of the statevector, only statevector simulator devices can be used.
- Only expectation values are supported as measurements.
- Does not work for parametrized observables like `Hamiltonian` or `Hermitian`.

Parameters
`tape` (*.QuantumTape*) – circuit that the function takes the gradient of

Keyword Arguments

- `starting_state` (*tensor_like*) – post-forward pass state to start execution with. It should be complex-valued. Takes precedence over `use_device_state`.
- `use_device_state` (*bool*) – use current device state to initialize. A forward pass of the same circuit should be the last thing the device has executed. If a `starting_state` is provided, that takes precedence.

Returns
the derivative of the tape with respect to trainable parameters. Dimensions are `(len(observables), len(trainable_params))`.

Return type
array or tuple[array]

Raises
`QuantumFunctionError` – if the input tape has measurements that are not expectation values or contains a multi-parameter operation aside from `Rot`

`analytic_probability`(*wires=None*)

Return the (marginal) probability of each computational basis state from the last run of the device.

PennyLane uses the convention $|q_0, q_1, \dots, q_{N-1}\rangle$ where q_0 is the most significant bit.

If no wires are specified, then all the basis states representable by the device are considered and no marginalization takes place.

Note: *marginal_prob()* may be used as a utility method to calculate the marginal probability distribution.

Parameters
`wires` (*Iterable[Number, str], Number, str, Wires*) – wires to return marginal probabilities for. Wires not provided are traced out of the system.

Returns
list of the probabilities

Return type
array[float]

`apply`(*operations: Sequence[Operation]*, *rotations: Sequence[Operation] | None = None*, *use_unique_params: bool = False*, ***, *trainable_indices: frozenset[int] | None = None*, ***run_kwargs*) → Circuit

Instantiate Braket Circuit object.

`batch_execute`(*circuits*, ***run_kwargs*)

Execute a batch of quantum circuits on the device.

The circuits are represented by tapes, and they are executed one-by-one using the device's `execute` method. The results are collected in a list.

For plugin developers: This function should be overwritten if the device can efficiently run multiple circuits on a backend, for example using parallel and/or asynchronous executions.

Parameters
`circuits` (*list[QuantumTape]*) – circuits to execute on the device

Returns
list of measured value(s)

Return type
list[array[float]]

`batch_transform`(*circuit: QuantumTape*)

Apply a differentiable batch transform for preprocessing a circuit prior to execution. This method is called directly by the QNode, and should be overwritten if the device requires a transform that generates multiple circuits prior to execution.

By default, this method contains logic for generating multiple circuits, one per term, of a circuit that terminates in `expval(H)`, if the underlying device does not support Hamiltonian expectation values, or if the device requires finite shots.

> **Warning:** This method will be tracked by autodifferentiation libraries, such as Autograd, JAX, TensorFlow, and Torch. Please make sure to use `qml.math` for autodiff-agnostic tensor processing if required.

Parameters
`circuit` (*.QuantumTape*) – the circuit to preprocess

Returns
Returns a tuple containing the sequence of circuits to be executed, and a post-processing function to be applied to the list of evaluated circuit results.

Return type
tuple[Sequence[.QuantumTape], callable]

`capabilities`()

Add support for AG on sv1

`check_validity`(*queue*, *observables*)

Check validity of pulse operations before running the standard check_validity function

Checks whether the operations and observables in queue are all supported by the device. Runs the standard check_validity function for a PennyLane device, and an additional check to validate any pulse-operations in the form of a ParametrizedEvolution operation.

Parameters

- **queue** (*Iterable[Operation]*) – quantum operation objects which are intended to be applied on the device
- **observables** (*Iterable[Observable]*) – observables which are intended to be evaluated on the device

Raises

- **DeviceError** – if there are operations in the queue or observables that the device does not support
- **RuntimeError** – if there are ParametrizedEvolution operations in the queue that are not supported because of invalid pulse parameters

`classical_shadow`(*obs*, *circuit*)

Returns the measured bits and recipes in the classical shadow protocol.

The protocol is described in detail in the classical shadows paper. This measurement process returns the randomized Pauli measurements (the `recipes`) that are performed for each qubit and snapshot as an integer:

- 0 for Pauli X,
- 1 for Pauli Y, and
- 2 for Pauli Z.

It also returns the measurement results (the `bits`); 0 if the 1 eigenvalue is sampled, and 1 if the -1 eigenvalue is sampled.

The device shots are used to specify the number of snapshots. If `T` is the number of shots and `n` is the number of qubits, then both the measured bits and the Pauli measurements have shape `(T, n)`.

This implementation is device-agnostic and works by executing single-shot tapes containing randomized Pauli observables. Devices should override this if they can offer cleaner or faster implementations.

See also:

`classical_shadow()`

Parameters

- **obs** (*ClassicalShadowMP*) – The classical shadow measurement process
- **circuit** (*QuantumTape*) – The quantum tape that is being executed

Returns

A tensor with shape `(2, T, n)`, where the first row represents the measured bits and the second represents the recipes used.

Return type

tensor_like[int]

custom_expand(*fn*)

Register a custom expansion function for the device.

Example

```
dev = qml.device("default.qubit.legacy", wires=2)

@dev.custom_expand
def my_expansion_function(self, tape, max_expansion=10):
    ...
    # can optionally call the default device expansion
    tape = self.default_expand_fn(tape, max_expansion=max_expansion)
    return tape
```

The custom device expansion function must have arguments `self` (the device object), `tape` (the input circuit to transform and execute), and `max_expansion` (the number of times the circuit should be expanded).

The default *default_expand_fn()* method of the original device may be called. It is highly recommended to call this before returning, to ensure that the expanded circuit is supported on the device.

default_expand_fn(*circuit*, *max_expansion=10*)

Method for expanding or decomposing an input circuit. This method should be overwritten if custom expansion logic is required.

By default, this method expands the tape if:

- state preparation operations are called mid-circuit,
- nested tapes are present,
- any operations are not supported on the device, or
- multiple observables are measured on the same wire.

Parameters

- **circuit** (*.QuantumTape*) – the circuit to expand.
- **max_expansion** (*int*) – The number of times the circuit should be expanded. Expansion occurs when an operation or measurement is not supported, and results in a gate decomposition. If any operations in the decomposition remain unsupported by the device, another expansion occurs.

Returns

The expanded/decomposed circuit, such that the device will natively support all operations.

Return type

.QuantumTape

define_wire_map(*wires*)

Create the map from user-provided wire labels to the wire labels used by the device.

The default wire map maps the user wire labels to wire labels that are consecutive integers.

However, by overwriting this function, devices can specify their preferred, non-consecutive and/or non-integer wire labels.

Parameters

wires (*Wires*) – user-provided wires for this device

Returns

dictionary specifying the wire map

Return type
OrderedDict

Example

```
>>> dev = device('my.device', wires=['b', 'a'])
>>> dev.wire_map()
OrderedDict( [(<Wires = ['a']>, <Wires = [0]>), (<Wires = ['b']>, <Wires = [1]>
↪)])
```

density_matrix(*wires*)

Returns the reduced density matrix over the given wires.

Parameters
wires (*Wires*) – wires of the reduced system

Returns
complex array of shape `(2 ** len(wires), 2 ** len(wires))` representing the reduced density matrix of the state prior to measurement.

Return type
array[complex]

estimate_probability(*wires=None*, *shot_range=None*, *bin_size=None*)

Return the estimated probability of each computational basis state using the generated samples.

Parameters

- **wires** (*Iterable[Number, str], Number, str, Wires*) – wires to calculate marginal probabilities for. Wires not provided are traced out of the system.
- **shot_range** (*tuple[int]*) – 2-tuple of integers specifying the range of samples to use. If not specified, all samples are used.
- **bin_size** (*int*) – Divides the shot range into bins of size `bin_size`, and returns the measurement statistic separately over each bin. If not provided, the entire shot range is treated as a single bin.

Returns
list of the probabilities

Return type
array[float]

execute(*circuit: QuantumTape*, *compute_gradient=False*, ***run_kwargs*) → ndarray

It executes a queue of quantum operations on the device and then measure the given observables.

For plugin developers: instead of overwriting this, consider implementing a suitable subset of

- *apply()*
- *generate_samples()*
- *probability()*

Additional keyword arguments may be passed to this method that can be utilised by *apply()*. An example would be passing the `QNode` hash that can be used later for parametric compilation.

Parameters
circuit (*QuantumTape*) – circuit to execute on the device

Raises
QuantumFunctionError – if the value of `return_type` is not supported

Returns
measured value(s)

Return type
array[float]

execute_and_gradients(*circuits*, ***kwargs*)

Execute a list of circuits and calculate their gradients. Returns a list of circuit results and a list of gradients/jacobians, one of each for each circuit in circuits.

The gradient is returned as a list of floats, 1 float for every instance of a trainable parameter in a gate in the circuit. Functions like qml.grad or qml.jacobian then use that format to generate a per-parameter format.

execution_context()

The device execution context used during calls to `execute()`.

You can overwrite this function to return a context manager in case your quantum library requires that; all operations and method calls (including `apply()` and `expval()`) are then evaluated within the context of this context manager (see the source of `execute()` for more details).

expand_fn(*circuit*, *max_expansion=10*)

Method for expanding or decomposing an input circuit. Can be the default or a custom expansion method, see `Device.default_expand_fn()` and `Device.custom_expand()` for more details.

Parameters

- **circuit** (*.QuantumTape*) – the circuit to expand.
- **max_expansion** (*int*) – The number of times the circuit should be expanded. Expansion occurs when an operation or measurement is not supported, and results in a gate decomposition. If any operations in the decomposition remain unsupported by the device, another expansion occurs.

Returns
The expanded/decomposed circuit, such that the device will natively support all operations.

Return type
.QuantumTape

expval(*observable*, *shot_range=None*, *bin_size=None*)

Returns the expectation value of observable on specified wires.

Note: all arguments accept _lists_, which indicate a tensor product of observables.

Parameters

- **observable** (*str or list[str]*) – name of the observable(s)
- **wires** (*Wires*) – wires the observable(s) are to be measured on
- **par** (*tuple or list[tuple]]*) – parameters for the observable(s)

Returns
expectation value $A = \psi A\psi$

Return type
float

static generate_basis_states(*num_wires*, *dtype=<class 'numpy.uint32'>*)

Generates basis states in binary representation according to the number of wires specified.

The states_to_binary method creates basis states faster (for larger systems at times over x25 times faster) than the approach using `itertools.product`, at the expense of using slightly more memory.

Due to the large size of the integer arrays for more than 32 bits, memory allocation errors may arise in the states_to_binary method. Hence we constraint the dtype of the array to represent unsigned integers on 32 bits. Due to this constraint, an overflow occurs for 32 or more wires, therefore this approach is used only for fewer wires.

For smaller number of wires speed is comparable to the next approach (using `itertools.product`), hence we resort to that one for testing purposes.

Parameters

- **num_wires** (*int*) – the number wires
- **dtype=np.uint32** (*type*) – the data type of the arrays to use

Returns
the sampled basis states

Return type
array[int]

`generate_samples()`

Returns the computational basis samples generated for all wires.

Note that PennyLane uses the convention $|q_0, q_1, \dots, q_{N-1}\rangle$ where q_0 is the most significant bit.

> **Warning:** This method should be overwritten on devices that generate their own computational basis samples, with the resulting computational basis samples stored as `self._samples`.

Returns
array of samples in the shape `(dev.shots, dev.num_wires)`

Return type
array[complex]

`gradients`(*circuits*, *method='jacobian'*, ***kwargs*)

Return the gradients of a batch of quantum circuits on the device.

The gradient method `method` is called sequentially for each circuit, and the corresponding Jacobians are collected in a list.

For plugin developers: This method should be overwritten if the device can efficiently compute the gradient of multiple circuits on a backend, for example using parallel and/or asynchronous executions.

Parameters

- **circuits** (*list[.tape.QuantumTape]*) – circuits to execute on the device
- **method** (*str*) – the device method to call to compute the Jacobian of a single circuit
- ****kwargs** – keyword argument to pass when calling `method`

Returns
List of Jacobians. Returned Jacobians should be of shape `(output_shape, num_params)`.

Return type
list[array[float]]

`map_wires`(*wires*)

Map the wire labels of wires using this device's wire map.

Parameters
`wires` (*Wires*) – wires whose labels we want to map to the device's internal labelling scheme

Returns
wires with new labels

Return type
Wires

`marginal_prob`(*prob*, *wires=None*)

Return the marginal probability of the computational basis states by summing the probabiliites on the non-specified wires.

If no wires are specified, then all the basis states representable by the device are considered and no marginalization takes place.

Note: If the provided wires are not in the order as they appear on the device, the returned marginal probabilities take this permutation into account.

For example, if the addressable wires on this device are `Wires([0, 1, 2])` and this function gets passed `wires=[2, 0]`, then the returned marginal probability vector will take this 'reversal' of the two wires into account:

$$\mathbb{P}^{(2,0)} = [|00\rangle, |10\rangle, |01\rangle, |11\rangle]$$

Parameters

- `prob` – The probabilities to return the marginal probabilities for
- `wires` (*Iterable[Number, str], Number, str, Wires*) – wires to return marginal probabilities for. Wires not provided are traced out of the system.

Returns
array of the resulting marginal probabilities.

Return type
array[float]

`mutual_info`(*wires0*, *wires1*, *log_base*)

Returns the mutual information prior to measurement:

$$I(A,B) = S(\rho^A) + S(\rho^B) - S(\rho^{AB})$$

where S is the von Neumann entropy.

Parameters

- `wires0` (*Wires*) – wires of the first subsystem
- `wires1` (*Wires*) – wires of the second subsystem
- `log_base` (*float*) – base to use in the logarithm

Returns
the mutual information

Return type
float

order_wires(*subset_wires*)

Given some subset of device wires return a Wires object with the same wires; sorted according to the device wire map.

Parameters
`subset_wires` (*Wires*) – The subset of device wires (in any order).

Raises
`ValueError` – Could not find some or all subset wires subset_wires in device wires device_wires.

Returns
a new Wires object containing the re-ordered wires set

Return type
ordered_wires (Wires)

post_apply()

Called during `execute()` after the individual operations have been executed.

post_measure()

Called during `execute()` after the individual observables have been measured.

pre_apply()

Called during `execute()` before the individual operations are executed.

pre_measure()

Called during `execute()` before the individual observables are measured.

probability(*wires=None*, *shot_range=None*, *bin_size=None*)

Return either the analytic probability or estimated probability of each computational basis state.

Devices that require a finite number of shots always return the estimated probability.

Parameters
`wires` (*Iterable[Number, str], Number, str, Wires*) – wires to return marginal probabilities for. Wires not provided are traced out of the system.

Returns
list of the probabilities

Return type
array[float]

reset()

Reset the backend state.

After the reset, the backend should be as if it was just constructed. Most importantly the quantum state is reset to its initial value.

sample(*observable*, *shot_range=None*, *bin_size=None*, *counts=False*)

Return samples of an observable.

Parameters

- `observable` (*Observable*) – the observable to sample
- `shot_range` (*tuple[int]*) – 2-tuple of integers specifying the range of samples to use. If not specified, all samples are used.

- **bin_size** (*int*) – Divides the shot range into bins of size bin_size, and returns the measurement statistic separately over each bin. If not provided, the entire shot range is treated as a single bin.
- **counts** (*bool*) – whether counts (True) or raw samples (False) should be returned

Raises
EigvalsUndefinedError – if no information is available about the eigenvalues of the observable

Returns
samples in an array of dimension (shots,) or counts

Return type
Union[array[float], dict, list[dict]]

sample_basis_states(*number_of_states*, *state_probability*)

Sample from the computational basis states based on the state probability.

This is an auxiliary method to the generate_samples method.

Parameters

- **number_of_states** (*int*) – the number of basis states to sample from
- **state_probability** (*array[float]*) – the computational basis probability vector

Returns
the sampled basis states

Return type
array[int]

shadow_expval(*obs*, *circuit*)

Compute expectation values using classical shadows in a differentiable manner.

Please refer to shadow_expval() for detailed documentation.

Parameters

- **obs** (*ClassicalShadowMP*) – The classical shadow expectation value measurement process
- **circuit** (*QuantumTape*) – The quantum tape that is being executed

Returns
expectation value estimate.

Return type
float

shot_vec_statistics(*circuit: QuantumTape*)

Process measurement results from circuit execution using a device with a shot vector and return statistics.

This is an auxiliary method of execute and uses statistics.

When using shot vectors, measurement results for each item of the shot vector are contained in a tuple.

Parameters
circuit (*QuantumTape*) – circuit to execute on the device

Raises
QuantumFunctionError – if the value of return_type is not supported

Returns
stastics for each shot item from the shot vector

Return type
tuple

`static states_to_binary`(*samples*, *num_wires*, *dtype=<class 'numpy.int64'>*)

Convert basis states from base 10 to binary representation.

This is an auxiliary method to the generate_samples method.

Parameters

- **samples** (*array[int]*) – samples of basis states in base 10 representation
- **num_wires** (*int*) – the number of qubits
- **dtype** (*type*) – Type of the internal integer array to be used. Can be important to specify for large systems for memory allocation purposes.

Returns
basis states in binary representation

Return type
array[int]

`statistics`(*braket_result: GateModelQuantumTaskResult*, *measurements: Sequence[MeasurementProcess]*) → list[float]

Processes measurement results from a Braket task result and returns statistics.

Parameters

- **braket_result** (*GateModelQuantumTaskResult*) – the Braket task result
- **measurements** (*Sequence[MeasurementProcess]*) – the list of measurements

Raises
QuantumFunctionError – if the value of `return_type` is not supported.

Returns
the corresponding statistics

Return type
list[float]

`supports_observable`(*observable*)

Checks if an observable is supported by this device. Raises a ValueError,
if not a subclass or string of an Observable was passed.

Parameters
observable (*type or str*) – observable to be checked

Raises
ValueError – if *observable* is not a `Observable` class or string

Returns
`True` iff supplied observable is supported

Return type
bool

`supports_operation`(*operation*)

Checks if an operation is supported by this device.

Parameters
`operation` (*type or str*) – operation to be checked

Raises
`ValueError` – if *operation* is not a `Operation` class or string

Returns
`True` if supplied operation is supported

Return type
bool

`var`(*observable*, *shot_range=None*, *bin_size=None*)

Returns the variance of observable on specified wires.

Note: all arguments support _lists_, which indicate a tensor product of observables.

Parameters

- `observable` (*str or list[str]*) – name of the observable(s)
- `wires` (*Wires*) – wires the observable(s) is to be measured on
- `par` (*tuple or list[tuple]]*) – parameters for the observable(s)

Raises
`NotImplementedError` – if the device does not support variance computation

Returns
variance $\mathrm{var}(A) = \psi A^2 \psi - \psi A \psi^2$

Return type
float

`vn_entropy`(*wires*, *log_base*)

Returns the Von Neumann entropy prior to measurement.

$$S(\rho) = -\mathrm{Tr}(\rho \log(\rho))$$

Parameters

- `wires` (*Wires*) – Wires of the considered subsystem.
- `log_base` (*float*) – Base for the logarithm, default is None the natural logarithm is used in this case.

Returns
returns the Von Neumann entropy

Return type
float

BraketLocalAhsDevice

class BraketLocalAhsDevice(*wires: int | Iterable*, *, *shots: int | Shots = Shots.DEFAULT*)

Bases: `BraketAhsDevice`

Amazon Braket LocalSimulator AHS device for PennyLane.

Runs programs on Braket's local AHS simulator. Can be used to emulate the *BraketAwsAhsDevice*.

Parameters

- **wires** (*int or Iterable[int, str]*) – Number of subsystems represented by the device, or iterable that contains unique labels for the subsystems as numbers (i.e., `[-1, 0, 2]`) or strings (`['ancilla', 'q1', 'q2']`).
- **shots** (*int or Shots.DEFAULT*) – Number of executions to run to aquire measurements. Default: Shots.DEFAULT

Note: It is important to keep track of units when specifying electromagnetic pulses for hardware control. The frequency and amplitude provided in PennyLane for Rydberg atom systems are expected to be in units of MHz, time in microseconds, phase in radians, and distance in micrometers. All of these will be converted to SI units internally as needed for upload to the hardware, and frequency will be converted to angular frequency (multiplied by 2π).

When reading hardware specifications from the Braket backend, bear in mind that all units are SI and frequencies are in rad/s. This conversion is done when creating a pulse program for upload, and units in the PennyLane functions should follow the conventions specified in the PennyLane docs to ensure correct unit conversion. See rydberg_interaction and rydberg_drive in Pennylane for specification of expected input units, and examples for creating hardware compatible ParametrizedEvolution operators in PennyLane.

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ahs_program	
analytic	Whether shots is None or not.
author	
circuit_hash	The hash of the circuit upon the last execution.
measurement_map	Mapping used to override the logic of measurement processes.
name	
num_executions	Number of times this device is executed by the evaluation of QNodes running on this device
obs_queue	The observables to be measured and returned.
observables	
op_queue	The operation queue to be applied.
operations	
parameters	Mapping from free parameter index to the list of `Operations` in the device queue that depend on it.
pennylane_requires	
register	Register a virtual subclass of an ABC.
result	
settings	Dictionary of constants set by the hardware.
short_name	
shot_vector	Returns the shot vector, a sparse representation of the shot sequence used by the device when evaluating QNodes.
shots	Number of circuit evaluations/random samples used to estimate expectation values of observables
state	Returns the state vector of the circuit prior to measurement.
stopping_condition	Returns the stopping condition for the device.
task	
version	
wire_map	Ordered dictionary that defines the map from user-provided wire labels to the wire labels used on this device
wires	All wires that can be addressed on this device

ahs_program

analytic

Whether shots is None or not. Kept for backwards compatability.

author = 'Xanadu Inc.'

circuit_hash

The hash of the circuit upon the last execution.

This can be used by devices in *apply()* for parametric compilation.

measurement_map = {}

Mapping used to override the logic of measurement processes. The dictionary maps a measurement class to a string containing the name of a device's method that overrides the measurement process. The method defined by the device should have the following arguments:

- measurement (MeasurementProcess): measurement to override
- **shot_range (tuple[int]): 2-tuple of integers specifying the range of samples**
  to use. If not specified, all samples are used.
- **bin_size (int): Divides the shot range into bins of size bin_size, and**
  returns the measurement statistic separately over each bin. If not provided, the entire shot range is treated as a single bin.

Note: When overriding the logic of a MeasurementTransform, the method defined by the device should only have a single argument:

- tape: quantum tape to transform

Example:

Let's create a device that inherits from DefaultQubitLegacy and overrides the logic of the *qml.sample* measurement. To do so we will need to update the measurement_map dictionary:

```
class NewDevice(DefaultQubitLegacy):
    def __init__(self, wires, shots):
        super().__init__(wires=wires, shots=shots)
        self.measurement_map[SampleMP] = "sample_measurement"

    def sample_measurement(self, measurement, shot_range=None, bin_size=None):
        return 2
```

```
>>> dev = NewDevice(wires=2, shots=1000)
>>> @qml.qnode(dev)
... def circuit():
...     return qml.sample()
>>> circuit()
tensor(2, requires_grad=True)
```

name = 'Braket LocalSimulator for AHS in PennyLane'

num_executions

Number of times this device is executed by the evaluation of QNodes running on this device

Returns
number of executions

Return type
int

obs_queue

The observables to be measured and returned.

Note that this property can only be accessed within the execution context of *execute()*.

Raises
`ValueError` – if outside of the execution context

Returns
list[~.operation.Observable]

observables = {'Hadamard', 'Hermitian', 'Identity', 'PauliX', 'PauliY', 'PauliZ', 'Prod', 'Projector', 'Sprod', 'Sum'}

op_queue

The operation queue to be applied.

Note that this property can only be accessed within the execution context of *execute()*.

Raises
`ValueError` – if outside of the execution context

Returns
list[~.operation.Operation]

operations = {'ParametrizedEvolution'}

parameters

Mapping from free parameter index to the list of `Operations` in the device queue that depend on it.

Note that this property can only be accessed within the execution context of *execute()*.

Raises
`ValueError` – if outside of the execution context

Returns
the mapping

Return type
dict[int->list[ParameterDependency]]

pennylane_requires = '>=0.30.0'

register

result

settings

Dictionary of constants set by the hardware.

Used to enable initializing hardware-consistent Hamiltonians by saving all the values that would need to be passed, i.e.:

```
>>> dev_remote = qml.device('braket.aws.ahs', wires=3)
>>> dev_pl = qml.device('default.qubit', wires=3)
>>> settings = dev_remote.settings
>>> H_int = qml.pulse.rydberg.rydberg_interaction(coordinates, **settings)
```

By passing the `settings` from the remote device to `rydberg_interaction`, an `H_int` Hamiltonian term is created using the constants specific to the hardware. This is relevant for simulating the remote device in PennyLane on the `default.qubit` device.

short_name = 'braket.local.ahs'

shot_vector

Returns the shot vector, a sparse representation of the shot sequence used by the device when evaluating QNodes.

Example

```
>>> dev = qml.device("default.qubit.legacy", wires=2, shots=[3, 1, 2, 2, 2, 2,␣
↪6, 1, 1, 5, 12, 10, 10])
>>> dev.shots
57
>>> dev.shot_vector
[ShotCopies(3 shots x 1),
 ShotCopies(1 shots x 1),
 ShotCopies(2 shots x 4),
 ShotCopies(6 shots x 1),
 ShotCopies(1 shots x 2),
 ShotCopies(5 shots x 1),
 ShotCopies(12 shots x 1),
 ShotCopies(10 shots x 2)]
```

The sparse representation of the shot sequence is returned, where tuples indicate the number of times a shot integer is repeated.

Type
list[*ShotCopies*]

shots

Number of circuit evaluations/random samples used to estimate expectation values of observables

state

Returns the state vector of the circuit prior to measurement.

Note: Only state vector simulators support this property. Please see the plugin documentation for more details.

stopping_condition

Returns the stopping condition for the device. The returned function accepts a queuable object (including a PennyLane operation and observable) and returns `True` if supported by the device.

Type
.BooleanFn

task

version = '0.34.0'

wire_map

Ordered dictionary that defines the map from user-provided wire labels to the wire labels used on this device

wires

All wires that can be addressed on this device

access_state([wires])	Check that the device has access to an internal state and return it if available.
active_wires(operators)	Returns the wires acted on by a set of operators.
adjoint_jacobian(tape[, starting_state, ...])	Implements the adjoint method outlined in Jones and Gacon to differentiate an input tape.
analytic_probability([wires])	Return the (marginal) probability of each computational basis state from the last run of the device.
apply(operations, **kwargs)	Convert the pulse operation to an AHS program and run on the connected device
batch_execute(circuits)	Execute a batch of quantum circuits on the device.
batch_transform(circuit)	Apply a differentiable batch transform for preprocessing a circuit prior to execution.
capabilities()	Get the capabilities of this device class.
check_validity(queue, observables)	Checks whether the operations and observables in queue are all supported by the device.
classical_shadow(obs, circuit)	Returns the measured bits and recipes in the classical shadow protocol.
create_ahs_program(evolution)	Create AHS program for upload to hardware from a ParametrizedEvolution
custom_expand(fn)	Register a custom expansion function for the device.
default_expand_fn(circuit[, max_expansion])	Method for expanding or decomposing an input circuit.
define_wire_map(wires)	Create the map from user-provided wire labels to the wire labels used by the device.
density_matrix(wires)	Returns the reduced density matrix over the given wires.
estimate_probability([wires, shot_range, ...])	Return the estimated probability of each computational basis state using the generated samples.
execute(circuit, **kwargs)	It executes a queue of quantum operations on the device and then measure the given observables.
execute_and_gradients(circuits[, method])	Execute a batch of quantum circuits on the device, and return both the results and the gradients.
execution_context()	The device execution context used during calls to *execute()*.
expand_fn(circuit[, max_expansion])	Method for expanding or decomposing an input circuit.
expval(observable[, shot_range, bin_size])	Returns the expectation value of observable on specified wires.
generate_basis_states(num_wires[, dtype])	Generates basis states in binary representation according to the number of wires specified.
generate_samples()	Returns the computational basis samples measured for all wires.
gradients(circuits[, method])	Return the gradients of a batch of quantum circuits on the device.
map_wires(wires)	Map the wire labels of wires using this device's wire map.
marginal_prob(prob[, wires])	Return the marginal probability of the computational basis states by summing the probabiliites on the non-specified wires.
mutual_info(wires0, wires1, log_base)	Returns the mutual information prior to measurement:

continues on next page

Table 3 – continued from previous page

order_wires(subset_wires)	Given some subset of device wires return a Wires object with the same wires; sorted according to the device wire map.
post_apply()	Called during *execute()* after the individual operations have been executed.
post_measure()	Called during *execute()* after the individual observables have been measured.
pre_apply()	Called during *execute()* before the individual operations are executed.
pre_measure()	Called during *execute()* before the individual observables are measured.
probability([wires, shot_range, bin_size])	Return either the analytic probability or estimated probability of each computational basis state.
reset()	Reset the backend state.
sample(observable[, shot_range, bin_size, ...])	Return samples of an observable.
sample_basis_states(number_of_states, ...)	Sample from the computational basis states based on the state probability.
shadow_expval(obs, circuit)	Compute expectation values using classical shadows in a differentiable manner.
shot_vec_statistics(circuit)	Process measurement results from circuit execution using a device with a shot vector and return statistics.
states_to_binary(samples, num_wires[, dtype])	Convert basis states from base 10 to binary representation.
statistics(circuit[, shot_range, bin_size])	Process measurement results from circuit execution and return statistics.
supports_observable(observable)	Checks if an observable is supported by this device. Raises a ValueError,
supports_operation(operation)	Checks if an operation is supported by this device.
var(observable[, shot_range, bin_size])	Returns the variance of observable on specified wires.
vn_entropy(wires, log_base)	Returns the Von Neumann entropy prior to measurement.

access_state(*wires=None*)

Check that the device has access to an internal state and return it if available.

Parameters
wires (*Wires*) – wires of the reduced system

Raises
QuantumFunctionError – if the device is not capable of returning the state

Returns
the state or the density matrix of the device

Return type
array or tensor

static active_wires(*operators*)

Returns the wires acted on by a set of operators.

Parameters
operators (*list[Operation]*) – operators for which we are gathering the active wires

Returns
wires activated by the specified operators

Return type
Wires

`adjoint_jacobian`(*tape: QuantumTape*, *starting_state=None*, *use_device_state=False*)

Implements the adjoint method outlined in Jones and Gacon to differentiate an input tape.

After a forward pass, the circuit is reversed by iteratively applying adjoint gates to scan backwards through the circuit.

Note: The adjoint differentiation method has the following restrictions:

- As it requires knowledge of the statevector, only statevector simulator devices can be used.
- Only expectation values are supported as measurements.
- Does not work for parametrized observables like `Hamiltonian` or `Hermitian`.

Parameters
tape (*.QuantumTape*) – circuit that the function takes the gradient of

Keyword Arguments

- **starting_state** (*tensor_like*) – post-forward pass state to start execution with. It should be complex-valued. Takes precedence over `use_device_state`.
- **use_device_state** (*bool*) – use current device state to initialize. A forward pass of the same circuit should be the last thing the device has executed. If a `starting_state` is provided, that takes precedence.

Returns
the derivative of the tape with respect to trainable parameters. Dimensions are `(len(observables), len(trainable_params))`.

Return type
array or tuple[array]

Raises
QuantumFunctionError – if the input tape has measurements that are not expectation values or contains a multi-parameter operation aside from `Rot`

`analytic_probability`(*wires=None*)

Return the (marginal) probability of each computational basis state from the last run of the device.

PennyLane uses the convention $|q_0, q_1, \dots, q_{N-1}\rangle$ where q_0 is the most significant bit.

If no wires are specified, then all the basis states representable by the device are considered and no marginalization takes place.

Note: `marginal_prob()` may be used as a utility method to calculate the marginal probability distribution.

Parameters
wires (*Iterable[Number, str], Number, str, Wires*) – wires to return marginal probabilities for. Wires not provided are traced out of the system.

Returns
list of the probabilities

Return type
array[float]

`apply`(*operations: list[ParametrizedEvolution]*, ***kwargs*)

Convert the pulse operation to an AHS program and run on the connected device

Parameters
`operations` (*list[ParametrizedEvolution]*) – a list containing a single ParametrizedEvolution operator

`batch_execute`(*circuits*)

Execute a batch of quantum circuits on the device.

The circuits are represented by tapes, and they are executed one-by-one using the device's `execute` method. The results are collected in a list.

For plugin developers: This function should be overwritten if the device can efficiently run multiple circuits on a backend, for example using parallel and/or asynchronous executions.

Parameters
`circuits` (*list[QuantumTape]*) – circuits to execute on the device

Returns
list of measured value(s)

Return type
list[array[float]]

`batch_transform`(*circuit: QuantumTape*)

Apply a differentiable batch transform for preprocessing a circuit prior to execution. This method is called directly by the QNode, and should be overwritten if the device requires a transform that generates multiple circuits prior to execution.

By default, this method contains logic for generating multiple circuits, one per term, of a circuit that terminates in `expval(H)`, if the underlying device does not support Hamiltonian expectation values, or if the device requires finite shots.

> **Warning:** This method will be tracked by autodifferentiation libraries, such as Autograd, JAX, TensorFlow, and Torch. Please make sure to use `qml.math` for autodiff-agnostic tensor processing if required.

Parameters
`circuit` (*.QuantumTape*) – the circuit to preprocess

Returns
Returns a tuple containing the sequence of circuits to be executed, and a post-processing function to be applied to the list of evaluated circuit results.

Return type
tuple[Sequence[.QuantumTape], callable]

`classmethod capabilities`()

Get the capabilities of this device class.

Inheriting classes that change or add capabilities must override this method, for example via

```
@classmethod
def capabilities(cls):
    capabilities = super().capabilities().copy()
    capabilities.update(
        supports_a_new_capability=True,
    )
    return capabilities
```

Returns
results

Return type
dict[str->*]

check_validity(*queue*, *observables*)

Checks whether the operations and observables in queue are all supported by the device.

Parameters

- **queue** (*Iterable[Operation]*) – quantum operation objects which are intended to be applied on the device
- **observables** (*Iterable[Observable]*) – observables which are intended to be evaluated on the device

Raises
Exception – if there are operations in the queue or observables that the device does not support

classical_shadow(*obs*, *circuit*)

Returns the measured bits and recipes in the classical shadow protocol.

The protocol is described in detail in the classical shadows paper. This measurement process returns the randomized Pauli measurements (the `recipes`) that are performed for each qubit and snapshot as an integer:

- 0 for Pauli X,
- 1 for Pauli Y, and
- 2 for Pauli Z.

It also returns the measurement results (the `bits`); 0 if the 1 eigenvalue is sampled, and 1 if the -1 eigenvalue is sampled.

The device shots are used to specify the number of snapshots. If `T` is the number of shots and `n` is the number of qubits, then both the measured bits and the Pauli measurements have shape `(T, n)`.

This implementation is device-agnostic and works by executing single-shot tapes containing randomized Pauli observables. Devices should override this if they can offer cleaner or faster implementations.

See also:

`classical_shadow()`

Parameters

- **obs** (*ClassicalShadowMP*) – The classical shadow measurement process
- **circuit** (*QuantumTape*) – The quantum tape that is being executed

Returns
A tensor with shape `(2, T, n)`, where the first row represents the measured bits and the second represents the recipes used.

Return type
tensor_like[int]

`create_ahs_program`(*evolution: ParametrizedEvolution*)

Create AHS program for upload to hardware from a ParametrizedEvolution

Parameters
evolution (*ParametrizedEvolution*) – the PennyLane operator describing the pulse to be converted into an AnalogHamiltonianSimulation program

Returns

a program containing the register and drive
information for running an AHS task on simulation or hardware

Return type
AnalogHamiltonianSimulation

`custom_expand`(*fn*)

Register a custom expansion function for the device.

Example

```
dev = qml.device("default.qubit.legacy", wires=2)

@dev.custom_expand
def my_expansion_function(self, tape, max_expansion=10):
    ...
    # can optionally call the default device expansion
    tape = self.default_expand_fn(tape, max_expansion=max_expansion)
    return tape
```

The custom device expansion function must have arguments `self` (the device object), `tape` (the input circuit to transform and execute), and `max_expansion` (the number of times the circuit should be expanded).

The default *default_expand_fn()* method of the original device may be called. It is highly recommended to call this before returning, to ensure that the expanded circuit is supported on the device.

`default_expand_fn`(*circuit*, *max_expansion=10*)

Method for expanding or decomposing an input circuit. This method should be overwritten if custom expansion logic is required.

By default, this method expands the tape if:

- state preparation operations are called mid-circuit,
- nested tapes are present,
- any operations are not supported on the device, or
- multiple observables are measured on the same wire.

Parameters

- **circuit** (*.QuantumTape*) – the circuit to expand.

- **max_expansion** (*int*) – The number of times the circuit should be expanded. Expansion occurs when an operation or measurement is not supported, and results in a gate decomposition. If any operations in the decomposition remain unsupported by the device, another expansion occurs.

Returns
The expanded/decomposed circuit, such that the device will natively support all operations.

Return type
.QuantumTape

define_wire_map(*wires*)

Create the map from user-provided wire labels to the wire labels used by the device.

The default wire map maps the user wire labels to wire labels that are consecutive integers.

However, by overwriting this function, devices can specify their preferred, non-consecutive and/or non-integer wire labels.

Parameters
wires (*Wires*) – user-provided wires for this device

Returns
dictionary specifying the wire map

Return type
OrderedDict

Example

```
>>> dev = device('my.device', wires=['b', 'a'])
>>> dev.wire_map()
OrderedDict( [(<Wires = ['a']>, <Wires = [0]>), (<Wires = ['b']>, <Wires = [1]>
↪)])
```

density_matrix(*wires*)

Returns the reduced density matrix over the given wires.

Parameters
wires (*Wires*) – wires of the reduced system

Returns
complex array of shape `(2 ** len(wires), 2 ** len(wires))` representing the reduced density matrix of the state prior to measurement.

Return type
array[complex]

estimate_probability(*wires=None*, *shot_range=None*, *bin_size=None*)

Return the estimated probability of each computational basis state using the generated samples.

Parameters

- **wires** (*Iterable[Number, str], Number, str, Wires*) – wires to calculate marginal probabilities for. Wires not provided are traced out of the system.
- **shot_range** (*tuple[int]*) – 2-tuple of integers specifying the range of samples to use. If not specified, all samples are used.
- **bin_size** (*int*) – Divides the shot range into bins of size `bin_size`, and returns the measurement statistic separately over each bin. If not provided, the entire shot range is treated as a single bin.

Returns
list of the probabilities

Return type
array[float]

execute(*circuit*, ***kwargs*)

It executes a queue of quantum operations on the device and then measure the given observables.

For plugin developers: instead of overwriting this, consider implementing a suitable subset of

- *apply()*
- *generate_samples()*
- *probability()*

Additional keyword arguments may be passed to this method that can be utilised by *apply()*. An example would be passing the `QNode` hash that can be used later for parametric compilation.

Parameters
circuit (*QuantumTape*) – circuit to execute on the device

Raises
QuantumFunctionError – if the value of `return_type` is not supported

Returns
measured value(s)

Return type
array[float]

execute_and_gradients(*circuits*, *method='jacobian'*, ***kwargs*)

Execute a batch of quantum circuits on the device, and return both the results and the gradients.

The circuits are represented by tapes, and they are executed one-by-one using the device's `execute` method. The results and the corresponding Jacobians are collected in a list.

For plugin developers: This method should be overwritten if the device can efficiently run multiple circuits on a backend, for example using parallel and/or asynchronous executions, and return both the results and the Jacobians.

Parameters

- **circuits** (*list[.tape.QuantumTape]*) – circuits to execute on the device
- **method** (*str*) – the device method to call to compute the Jacobian of a single circuit
- ****kwargs** – keyword argument to pass when calling `method`

Returns
Tuple containing list of measured value(s) and list of Jacobians. Returned Jacobians should be of shape `(output_shape, num_params)`.

Return type
tuple[list[array[float]], list[array[float]]]

execution_context()

The device execution context used during calls to *execute()*.

You can overwrite this function to return a context manager in case your quantum library requires that; all operations and method calls (including *apply()* and *expval()*) are then evaluated within the context of this context manager (see the source of *execute()* for more details).

expand_fn(*circuit*, *max_expansion=10*)

Method for expanding or decomposing an input circuit. Can be the default or a custom expansion method, see `Device.default_expand_fn()` and `Device.custom_expand()` for more details.

Parameters

- **circuit** (*.QuantumTape*) – the circuit to expand.
- **max_expansion** (*int*) – The number of times the circuit should be expanded. Expansion occurs when an operation or measurement is not supported, and results in a gate decomposition. If any operations in the decomposition remain unsupported by the device, another expansion occurs.

Returns

The expanded/decomposed circuit, such that the device will natively support all operations.

Return type

.QuantumTape

expval(*observable*, *shot_range=None*, *bin_size=None*)

Returns the expectation value of observable on specified wires.

Note: all arguments accept _lists_, which indicate a tensor product of observables.

Parameters

- **observable** (*str or list[str]*) – name of the observable(s)
- **wires** (*Wires*) – wires the observable(s) are to be measured on
- **par** (*tuple or list[tuple]]*) – parameters for the observable(s)

Returns

expectation value $A = \psi A\psi$

Return type

float

static generate_basis_states(*num_wires*, *dtype=<class 'numpy.uint32'>*)

Generates basis states in binary representation according to the number of wires specified.

The states_to_binary method creates basis states faster (for larger systems at times over x25 times faster) than the approach using `itertools.product`, at the expense of using slightly more memory.

Due to the large size of the integer arrays for more than 32 bits, memory allocation errors may arise in the states_to_binary method. Hence we constraint the dtype of the array to represent unsigned integers on 32 bits. Due to this constraint, an overflow occurs for 32 or more wires, therefore this approach is used only for fewer wires.

For smaller number of wires speed is comparable to the next approach (using `itertools.product`), hence we resort to that one for testing purposes.

Parameters

- **num_wires** (*int*) – the number wires
- **dtype=np.uint32** (*type*) – the data type of the arrays to use

Returns

the sampled basis states

Return type

array[int]

generate_samples()

Returns the computational basis samples measured for all wires.

Returns
array of samples in the shape `(dev.shots, dev.num_wires)`

Return type
array[complex]

gradients(*circuits*, *method='jacobian'*, ***kwargs*)

Return the gradients of a batch of quantum circuits on the device.

The gradient method `method` is called sequentially for each circuit, and the corresponding Jacobians are collected in a list.

For plugin developers: This method should be overwritten if the device can efficiently compute the gradient of multiple circuits on a backend, for example using parallel and/or asynchronous executions.

Parameters

- **circuits** (*list[.tape.QuantumTape]*) – circuits to execute on the device
- **method** (*str*) – the device method to call to compute the Jacobian of a single circuit
- ****kwargs** – keyword argument to pass when calling `method`

Returns
List of Jacobians. Returned Jacobians should be of shape `(output_shape, num_params)`.

Return type
list[array[float]]

map_wires(*wires*)

Map the wire labels of wires using this device's wire map.

Parameters
wires (*Wires*) – wires whose labels we want to map to the device's internal labelling scheme

Returns
wires with new labels

Return type
Wires

marginal_prob(*prob*, *wires=None*)

Return the marginal probability of the computational basis states by summing the probabiliites on the non-specified wires.

If no wires are specified, then all the basis states representable by the device are considered and no marginalization takes place.

Note: If the provided wires are not in the order as they appear on the device, the returned marginal probabilities take this permutation into account.

For example, if the addressable wires on this device are `Wires([0, 1, 2])` and this function gets passed `wires=[2, 0]`, then the returned marginal probability vector will take this 'reversal' of the two wires into account:

$$\mathbb{P}^{(2,0)} = [|00\rangle, |10\rangle, |01\rangle, |11\rangle]$$

Parameters

- **prob** – The probabilities to return the marginal probabilities for
- **wires** (*Iterable[Number, str], Number, str, Wires*) – wires to return marginal probabilities for. Wires not provided are traced out of the system.

Returns
array of the resulting marginal probabilities.

Return type
array[float]

mutual_info(*wires0*, *wires1*, *log_base*)

Returns the mutual information prior to measurement:

$$I(A,B) = S(\rho^A) + S(\rho^B) - S(\rho^{AB})$$

where S is the von Neumann entropy.

Parameters

- **wires0** (*Wires*) – wires of the first subsystem
- **wires1** (*Wires*) – wires of the second subsystem
- **log_base** (*float*) – base to use in the logarithm

Returns
the mutual information

Return type
float

order_wires(*subset_wires*)

Given some subset of device wires return a Wires object with the same wires; sorted according to the device wire map.

Parameters
subset_wires (*Wires*) – The subset of device wires (in any order).

Raises
ValueError – Could not find some or all subset wires subset_wires in device wires device_wires.

Returns
a new Wires object containing the re-ordered wires set

Return type
ordered_wires (Wires)

post_apply()

Called during *execute()* after the individual operations have been executed.

post_measure()

Called during *execute()* after the individual observables have been measured.

pre_apply()

Called during *execute()* before the individual operations are executed.

pre_measure()

Called during *execute()* before the individual observables are measured.

probability(*wires=None*, *shot_range=None*, *bin_size=None*)

Return either the analytic probability or estimated probability of each computational basis state.

Devices that require a finite number of shots always return the estimated probability.

Parameters

wires (*Iterable[Number, str], Number, str, Wires*) – wires to return marginal probabilities for. Wires not provided are traced out of the system.

Returns

list of the probabilities

Return type

array[float]

reset()

Reset the backend state.

After the reset, the backend should be as if it was just constructed. Most importantly the quantum state is reset to its initial value.

sample(*observable*, *shot_range=None*, *bin_size=None*, *counts=False*)

Return samples of an observable.

Parameters

- **observable** (*Observable*) – the observable to sample
- **shot_range** (*tuple[int]*) – 2-tuple of integers specifying the range of samples to use. If not specified, all samples are used.
- **bin_size** (*int*) – Divides the shot range into bins of size `bin_size`, and returns the measurement statistic separately over each bin. If not provided, the entire shot range is treated as a single bin.
- **counts** (*bool*) – whether counts (`True`) or raw samples (`False`) should be returned

Raises

EigvalsUndefinedError – if no information is available about the eigenvalues of the observable

Returns

samples in an array of dimension `(shots,)` or counts

Return type

Union[array[float], dict, list[dict]]

sample_basis_states(*number_of_states*, *state_probability*)

Sample from the computational basis states based on the state probability.

This is an auxiliary method to the generate_samples method.

Parameters

- **number_of_states** (*int*) – the number of basis states to sample from
- **state_probability** (*array[float]*) – the computational basis probability vector

Returns

the sampled basis states

Return type

array[int]

shadow_expval(*obs*, *circuit*)

Compute expectation values using classical shadows in a differentiable manner.

Please refer to `shadow_expval()` for detailed documentation.

Parameters

- **obs** (*ClassicalShadowMP*) – The classical shadow expectation value measurement process
- **circuit** (*QuantumTape*) – The quantum tape that is being executed

Returns
expectation value estimate.

Return type
float

shot_vec_statistics(*circuit: QuantumTape*)

Process measurement results from circuit execution using a device with a shot vector and return statistics.

This is an auxiliary method of execute and uses statistics.

When using shot vectors, measurement results for each item of the shot vector are contained in a tuple.

Parameters
circuit (*QuantumTape*) – circuit to execute on the device

Raises
QuantumFunctionError – if the value of `return_type` is not supported

Returns
stastics for each shot item from the shot vector

Return type
tuple

static states_to_binary(*samples*, *num_wires*, *dtype=<class 'numpy.int64'>*)

Convert basis states from base 10 to binary representation.

This is an auxiliary method to the generate_samples method.

Parameters

- **samples** (*array[int]*) – samples of basis states in base 10 representation
- **num_wires** (*int*) – the number of qubits
- **dtype** (*type*) – Type of the internal integer array to be used. Can be important to specify for large systems for memory allocation purposes.

Returns
basis states in binary representation

Return type
array[int]

statistics(*circuit: QuantumTape*, *shot_range=None*, *bin_size=None*)

Process measurement results from circuit execution and return statistics.

This includes returning expectation values, variance, samples, probabilities, states, and density matrices.

Parameters

- **circuit** (*QuantumTape*) – the quantum tape currently being executed

- **shot_range** (*tuple[int]*) – 2-tuple of integers specifying the range of samples to use. If not specified, all samples are used.
- **bin_size** (*int*) – Divides the shot range into bins of size `bin_size`, and returns the measurement statistic separately over each bin. If not provided, the entire shot range is treated as a single bin.

Raises
`QuantumFunctionError` – if the value of `return_type` is not supported

Returns
the corresponding statistics

Return type
Union[float, List[float]]

`supports_observable`(*observable*)

Checks if an observable is supported by this device. Raises a ValueError,
if not a subclass or string of an Observable was passed.

Parameters
observable (*type or str*) – observable to be checked

Raises
`ValueError` – if *observable* is not a `Observable` class or string

Returns
`True` iff supplied observable is supported

Return type
bool

`supports_operation`(*operation*)

Checks if an operation is supported by this device.

Parameters
operation (*type or str*) – operation to be checked

Raises
`ValueError` – if *operation* is not a `Operation` class or string

Returns
`True` if supplied operation is supported

Return type
bool

`var`(*observable*, *shot_range=None*, *bin_size=None*)

Returns the variance of observable on specified wires.

Note: all arguments support _lists_, which indicate a tensor product of observables.

Parameters

- **observable** (*str or list[str]*) – name of the observable(s)
- **wires** (*Wires*) – wires the observable(s) is to be measured on
- **par** (*tuple or list[tuple]]*) – parameters for the observable(s)

Raises
`NotImplementedError` – if the device does not support variance computation

Returns
variance $\mathrm{var}(A) = \psi A^2 \psi - \psi A \psi^2$

Return type
float

vn_entropy(*wires*, *log_base*)

Returns the Von Neumann entropy prior to measurement.

$$S(\rho) = -\mathrm{Tr}(\rho \log(\rho))$$

Parameters

- **wires** (*Wires*) – Wires of the considered subsystem.
- **log_base** (*float*) – Base for the logarithm, default is None the natural logarithm is used in this case.

Returns
returns the Von Neumann entropy

Return type
float

BraketLocalQubitDevice

class **BraketLocalQubitDevice**(*wires: int | Iterable*, *backend: str | BraketSimulator = 'default'*, *, *shots: int | None = None*, ***run_kwargs*)

Bases: `BraketQubitDevice`

Amazon Braket LocalSimulator qubit device for PennyLane.

Parameters

- **wires** (*int or Iterable[Number, str]]*) – Number of subsystems represented by the device, or iterable that contains unique labels for the subsystems as numbers (i.e., `[-1, 0, 2]`) or strings (`['ancilla', 'q1', 'q2']`).
- **backend** (*Union[str, BraketSimulator]*) – The name of the simulator backend or the actual simulator instance to use for simulation. Defaults to the `default` simulator backend name.
- **shots** (*int or None*) – Number of circuit evaluations or random samples included, to estimate expectation values of observables. If this value is set to `None` or `0`, then the device runs in analytic mode (calculations will be exact). Default: None
- ****run_kwargs** – Variable length keyword arguments for `braket.devices.Device.run()`.

analytic	Whether shots is None or not.
author	
circuit	The last circuit run on this device.
circuit_hash	The hash of the circuit upon the last execution.
measurement_map	Mapping used to override the logic of measurement processes.
name	
num_executions	Number of times this device is executed by the evaluation of QNodes running on this device
obs_queue	The observables to be measured and returned.
observables	set() -> new empty set object set(iterable) -> new set object
op_queue	The operation queue to be applied.
operations	The set of names of PennyLane operations that the device supports.
parameters	Mapping from free parameter index to the list of `Operations` in the device queue that depend on it.
pennylane_requires	
short_name	
shot_vector	Returns the shot vector, a sparse representation of the shot sequence used by the device when evaluating QNodes.
shots	Number of circuit evaluations/random samples used to estimate expectation values of observables
state	Returns the state vector of the circuit prior to measurement.
stopping_condition	Returns the stopping condition for the device.
task	The task corresponding to the last run circuit.
version	
wire_map	Ordered dictionary that defines the map from user-provided wire labels to the wire labels used on this device
wires	All wires that can be addressed on this device

analytic

Whether shots is None or not. Kept for backwards compatability.

author = 'Amazon Web Services'

circuit

The last circuit run on this device.

Type
Circuit

circuit_hash

The hash of the circuit upon the last execution.

This can be used by devices in *apply()* for parametric compilation.

measurement_map = {}

Mapping used to override the logic of measurement processes. The dictionary maps a measurement class to a string containing the name of a device's method that overrides the measurement process. The method defined by the device should have the following arguments:

- measurement (MeasurementProcess): measurement to override
- **shot_range (tuple[int]): 2-tuple of integers specifying the range of samples**
  to use. If not specified, all samples are used.
- **bin_size (int): Divides the shot range into bins of size `bin_size`, and**
  returns the measurement statistic separately over each bin. If not provided, the entire shot range is treated as a single bin.

Note: When overriding the logic of a `MeasurementTransform`, the method defined by the device should only have a single argument:

- tape: quantum tape to transform

Example:

Let's create a device that inherits from `DefaultQubitLegacy` and overrides the logic of the *qml.sample* measurement. To do so we will need to update the `measurement_map` dictionary:

```
class NewDevice(DefaultQubitLegacy):
    def __init__(self, wires, shots):
        super().__init__(wires=wires, shots=shots)
        self.measurement_map[SampleMP] = "sample_measurement"

    def sample_measurement(self, measurement, shot_range=None, bin_size=None):
        return 2
```

```
>>> dev = NewDevice(wires=2, shots=1000)
>>> @qml.qnode(dev)
... def circuit():
...     return qml.sample()
>>> circuit()
tensor(2, requires_grad=True)
```

name = 'Braket LocalSimulator for PennyLane'

num_executions

Number of times this device is executed by the evaluation of QNodes running on this device

Returns
number of executions

Return type
int

obs_queue

The observables to be measured and returned.

Note that this property can only be accessed within the execution context of *execute()*.

Raises
ValueError – if outside of the execution context

Returns
list[~.operation.Observable]

observables

op_queue

The operation queue to be applied.

Note that this property can only be accessed within the execution context of *execute()*.

Raises
`ValueError` – if outside of the execution context

Returns
list[~.operation.Operation]

operations

The set of names of PennyLane operations that the device supports.

Type
frozenset[str]

parameters

Mapping from free parameter index to the list of `Operations` in the device queue that depend on it.

Note that this property can only be accessed within the execution context of *execute()*.

Raises
`ValueError` – if outside of the execution context

Returns
the mapping

Return type
dict[int->list[ParameterDependency]]

pennylane_requires = '>=0.30.0'

short_name = 'braket.local.qubit'

shot_vector

Returns the shot vector, a sparse representation of the shot sequence used by the device when evaluating QNodes.

Example

```
>>> dev = qml.device("default.qubit.legacy", wires=2, shots=[3, 1, 2, 2, 2, 2,␣
↪6, 1, 1, 5, 12, 10, 10])
>>> dev.shots
57
>>> dev.shot_vector
[ShotCopies(3 shots x 1),
 ShotCopies(1 shots x 1),
 ShotCopies(2 shots x 4),
 ShotCopies(6 shots x 1),
 ShotCopies(1 shots x 2),
 ShotCopies(5 shots x 1),
 ShotCopies(12 shots x 1),
 ShotCopies(10 shots x 2)]
```

The sparse representation of the shot sequence is returned, where tuples indicate the number of times a shot integer is repeated.

Type
list[*ShotCopies*]

shots

Number of circuit evaluations/random samples used to estimate expectation values of observables

state

Returns the state vector of the circuit prior to measurement.

Note: Only state vector simulators support this property. Please see the plugin documentation for more details.

stopping_condition

Returns the stopping condition for the device. The returned function accepts a queuable object (including a PennyLane operation and observable) and returns `True` if supported by the device.

Type
.BooleanFn

task

The task corresponding to the last run circuit.

Type
QuantumTask

version = '1.24.2'

wire_map

Ordered dictionary that defines the map from user-provided wire labels to the wire labels used on this device

wires

All wires that can be addressed on this device

access_state([wires])	Check that the device has access to an internal state and return it if available.
active_wires(operators)	Returns the wires acted on by a set of operators.
adjoint_jacobian(tape[, starting_state, ...])	Implements the adjoint method outlined in Jones and Gacon to differentiate an input tape.
analytic_probability([wires])	Return the (marginal) probability of each computational basis state from the last run of the device.
apply(operations[, rotations, ...])	Instantiate Braket Circuit object.
batch_execute(circuits)	Execute a batch of quantum circuits on the device.
batch_transform(circuit)	Apply a differentiable batch transform for preprocessing a circuit prior to execution.
capabilities()	Get the capabilities of this device class.
check_validity(queue, observables)	Checks whether the operations and observables in queue are all supported by the device.
classical_shadow(obs, circuit)	Returns the measured bits and recipes in the classical shadow protocol.
custom_expand(fn)	Register a custom expansion function for the device.

continues on next page

Table 4 – continued from previous page

default_expand_fn(circuit[, max_expansion])	Method for expanding or decomposing an input circuit.
define_wire_map(wires)	Create the map from user-provided wire labels to the wire labels used by the device.
density_matrix(wires)	Returns the reduced density matrix over the given wires.
estimate_probability([wires, shot_range, ...])	Return the estimated probability of each computational basis state using the generated samples.
execute(circuit[, compute_gradient])	It executes a queue of quantum operations on the device and then measure the given observables.
execute_and_gradients(circuits[, method])	Execute a batch of quantum circuits on the device, and return both the results and the gradients.
execution_context()	The device execution context used during calls to execute().
expand_fn(circuit[, max_expansion])	Method for expanding or decomposing an input circuit.
expval(observable[, shot_range, bin_size])	Returns the expectation value of observable on specified wires.
generate_basis_states(num_wires[, dtype])	Generates basis states in binary representation according to the number of wires specified.
generate_samples()	Returns the computational basis samples generated for all wires.
gradients(circuits[, method])	Return the gradients of a batch of quantum circuits on the device.
map_wires(wires)	Map the wire labels of wires using this device's wire map.
marginal_prob(prob[, wires])	Return the marginal probability of the computational basis states by summing the probabiliites on the non-specified wires.
mutual_info(wires0, wires1, log_base)	Returns the mutual information prior to measurement:
order_wires(subset_wires)	Given some subset of device wires return a Wires object with the same wires; sorted according to the device wire map.
post_apply()	Called during execute() after the individual operations have been executed.
post_measure()	Called during execute() after the individual observables have been measured.
pre_apply()	Called during execute() before the individual operations are executed.
pre_measure()	Called during execute() before the individual observables are measured.
probability([wires, shot_range, bin_size])	Return either the analytic probability or estimated probability of each computational basis state.
reset()	Reset the backend state.
sample(observable[, shot_range, bin_size, ...])	Return samples of an observable.
sample_basis_states(number_of_states, ...)	Sample from the computational basis states based on the state probability.
shadow_expval(obs, circuit)	Compute expectation values using classical shadows in a differentiable manner.
shot_vec_statistics(circuit)	Process measurement results from circuit execution using a device with a shot vector and return statistics.

continues on next page

Table 4 – continued from previous page

`states_to_binary`(samples, num_wires[, dtype])	Convert basis states from base 10 to binary representation.
`statistics`(braket_result, measurements)	Processes measurement results from a Braket task result and returns statistics.
`supports_observable`(observable)	Checks if an observable is supported by this device. Raises a ValueError,
`supports_operation`(operation)	Checks if an operation is supported by this device.
`var`(observable[, shot_range, bin_size])	Returns the variance of observable on specified wires.
`vn_entropy`(wires, log_base)	Returns the Von Neumann entropy prior to measurement.

access_state(*wires=None*)

Check that the device has access to an internal state and return it if available.

Parameters
`wires` (*Wires*) – wires of the reduced system

Raises
`QuantumFunctionError` – if the device is not capable of returning the state

Returns
the state or the density matrix of the device

Return type
array or tensor

static active_wires(*operators*)

Returns the wires acted on by a set of operators.

Parameters
`operators` (*list[Operation]*) – operators for which we are gathering the active wires

Returns
wires activated by the specified operators

Return type
Wires

adjoint_jacobian(*tape: QuantumTape*, *starting_state=None*, *use_device_state=False*)

Implements the adjoint method outlined in Jones and Gacon to differentiate an input tape.

After a forward pass, the circuit is reversed by iteratively applying adjoint gates to scan backwards through the circuit.

Note: The adjoint differentiation method has the following restrictions:

- As it requires knowledge of the statevector, only statevector simulator devices can be used.
- Only expectation values are supported as measurements.
- Does not work for parametrized observables like `Hamiltonian` or `Hermitian`.

Parameters
`tape` (*.QuantumTape*) – circuit that the function takes the gradient of

Keyword Arguments

- **starting_state** (*tensor_like*) – post-forward pass state to start execution with. It should be complex-valued. Takes precedence over `use_device_state`.
- **use_device_state** (*bool*) – use current device state to initialize. A forward pass of the same circuit should be the last thing the device has executed. If a `starting_state` is provided, that takes precedence.

Returns
the derivative of the tape with respect to trainable parameters. Dimensions are `(len(observables), len(trainable_params))`.

Return type
array or tuple[array]

Raises
QuantumFunctionError – if the input tape has measurements that are not expectation values or contains a multi-parameter operation aside from `Rot`

analytic_probability(*wires=None*)

Return the (marginal) probability of each computational basis state from the last run of the device.

PennyLane uses the convention $|q_0, q_1, \dots, q_{N-1}\rangle$ where q_0 is the most significant bit.

If no wires are specified, then all the basis states representable by the device are considered and no marginalization takes place.

Note: *marginal_prob()* may be used as a utility method to calculate the marginal probability distribution.

Parameters
wires (*Iterable[Number, str], Number, str, Wires*) – wires to return marginal probabilities for. Wires not provided are traced out of the system.

Returns
list of the probabilities

Return type
array[float]

apply(*operations: Sequence[Operation]*, *rotations: Sequence[Operation] | None = None*, *use_unique_params: bool = False*, ***, *trainable_indices: frozenset[int] | None = None*, ***run_kwargs*) → Circuit

Instantiate Braket Circuit object.

batch_execute(*circuits*)

Execute a batch of quantum circuits on the device.

The circuits are represented by tapes, and they are executed one-by-one using the device's `execute` method. The results are collected in a list.

For plugin developers: This function should be overwritten if the device can efficiently run multiple circuits on a backend, for example using parallel and/or asynchronous executions.

Parameters
circuits (*list[QuantumTape]*) – circuits to execute on the device

Returns
list of measured value(s)

Return type
list[array[float]]

batch_transform(*circuit: QuantumTape*)

Apply a differentiable batch transform for preprocessing a circuit prior to execution. This method is called directly by the QNode, and should be overwritten if the device requires a transform that generates multiple circuits prior to execution.

By default, this method contains logic for generating multiple circuits, one per term, of a circuit that terminates in `expval(H)`, if the underlying device does not support Hamiltonian expectation values, or if the device requires finite shots.

> **Warning:** This method will be tracked by autodifferentiation libraries, such as Autograd, JAX, TensorFlow, and Torch. Please make sure to use `qml.math` for autodiff-agnostic tensor processing if required.

Parameters
circuit (*.QuantumTape*) – the circuit to preprocess

Returns
Returns a tuple containing the sequence of circuits to be executed, and a post-processing function to be applied to the list of evaluated circuit results.

Return type
tuple[Sequence[.QuantumTape], callable]

classmethod capabilities()

Get the capabilities of this device class.

Inheriting classes that change or add capabilities must override this method, for example via

```
@classmethod
def capabilities(cls):
    capabilities = super().capabilities().copy()
    capabilities.update(
        supports_a_new_capability=True,
    )
    return capabilities
```

Returns
results

Return type
dict[str->*]

check_validity(*queue*, *observables*)

Checks whether the operations and observables in queue are all supported by the device.

Parameters

- **queue** (*Iterable[Operation]*) – quantum operation objects which are intended to be applied on the device
- **observables** (*Iterable[Observable]*) – observables which are intended to be evaluated on the device

Raises

`DeviceError` – if there are operations in the queue or observables that the device does not support

`classical_shadow`(*obs*, *circuit*)

Returns the measured bits and recipes in the classical shadow protocol.

The protocol is described in detail in the classical shadows paper. This measurement process returns the randomized Pauli measurements (the `recipes`) that are performed for each qubit and snapshot as an integer:

- 0 for Pauli X,
- 1 for Pauli Y, and
- 2 for Pauli Z.

It also returns the measurement results (the `bits`); 0 if the 1 eigenvalue is sampled, and 1 if the -1 eigenvalue is sampled.

The device shots are used to specify the number of snapshots. If `T` is the number of shots and `n` is the number of qubits, then both the measured bits and the Pauli measurements have shape `(T, n)`.

This implementation is device-agnostic and works by executing single-shot tapes containing randomized Pauli observables. Devices should override this if they can offer cleaner or faster implementations.

See also:

`classical_shadow()`

Parameters

- **obs** (*ClassicalShadowMP*) – The classical shadow measurement process
- **circuit** (*QuantumTape*) – The quantum tape that is being executed

Returns

A tensor with shape `(2, T, n)`, where the first row represents the measured bits and the second represents the recipes used.

Return type

tensor_like[int]

`custom_expand`(*fn*)

Register a custom expansion function for the device.

Example

```
dev = qml.device("default.qubit.legacy", wires=2)

@dev.custom_expand
def my_expansion_function(self, tape, max_expansion=10):
    ...
    # can optionally call the default device expansion
    tape = self.default_expand_fn(tape, max_expansion=max_expansion)
    return tape
```

The custom device expansion function must have arguments `self` (the device object), `tape` (the input circuit to transform and execute), and `max_expansion` (the number of times the circuit should be expanded).

The default *`default_expand_fn()`* method of the original device may be called. It is highly recommended to call this before returning, to ensure that the expanded circuit is supported on the device.

default_expand_fn(*circuit*, *max_expansion=10*)

Method for expanding or decomposing an input circuit. This method should be overwritten if custom expansion logic is required.

By default, this method expands the tape if:

- state preparation operations are called mid-circuit,
- nested tapes are present,
- any operations are not supported on the device, or
- multiple observables are measured on the same wire.

Parameters

- **circuit** (*.QuantumTape*) – the circuit to expand.
- **max_expansion** (*int*) – The number of times the circuit should be expanded. Expansion occurs when an operation or measurement is not supported, and results in a gate decomposition. If any operations in the decomposition remain unsupported by the device, another expansion occurs.

Returns

The expanded/decomposed circuit, such that the device will natively support all operations.

Return type

.QuantumTape

define_wire_map(*wires*)

Create the map from user-provided wire labels to the wire labels used by the device.

The default wire map maps the user wire labels to wire labels that are consecutive integers.

However, by overwriting this function, devices can specify their preferred, non-consecutive and/or non-integer wire labels.

Parameters

wires (*Wires*) – user-provided wires for this device

Returns

dictionary specifying the wire map

Return type

OrderedDict

Example

```
>>> dev = device('my.device', wires=['b', 'a'])
>>> dev.wire_map()
OrderedDict( [(<Wires = ['a']>, <Wires = [0]>), (<Wires = ['b']>, <Wires = [1]>
↪)])
```

density_matrix(*wires*)

Returns the reduced density matrix over the given wires.

Parameters

wires (*Wires*) – wires of the reduced system

Returns

complex array of shape `(2 ** len(wires), 2 ** len(wires))` representing the reduced density matrix of the state prior to measurement.

Return type
array[complex]

`estimate_probability`(*wires=None*, *shot_range=None*, *bin_size=None*)

Return the estimated probability of each computational basis state using the generated samples.

Parameters

- **wires** (*Iterable[Number, str], Number, str, Wires*) – wires to calculate marginal probabilities for. Wires not provided are traced out of the system.
- **shot_range** (*tuple[int]*) – 2-tuple of integers specifying the range of samples to use. If not specified, all samples are used.
- **bin_size** (*int*) – Divides the shot range into bins of size `bin_size`, and returns the measurement statistic separately over each bin. If not provided, the entire shot range is treated as a single bin.

Returns
list of the probabilities

Return type
array[float]

`execute`(*circuit: QuantumTape*, *compute_gradient=False*, ***run_kwargs*) → ndarray

It executes a queue of quantum operations on the device and then measure the given observables.

For plugin developers: instead of overwriting this, consider implementing a suitable subset of

- *apply()*
- *generate_samples()*
- *probability()*

Additional keyword arguments may be passed to this method that can be utilised by *apply()*. An example would be passing the `QNode` hash that can be used later for parametric compilation.

Parameters
circuit (*QuantumTape*) – circuit to execute on the device

Raises
QuantumFunctionError – if the value of `return_type` is not supported

Returns
measured value(s)

Return type
array[float]

`execute_and_gradients`(*circuits*, *method='jacobian'*, ***kwargs*)

Execute a batch of quantum circuits on the device, and return both the results and the gradients.

The circuits are represented by tapes, and they are executed one-by-one using the device's `execute` method. The results and the corresponding Jacobians are collected in a list.

For plugin developers: This method should be overwritten if the device can efficiently run multiple circuits on a backend, for example using parallel and/or asynchronous executions, and return both the results and the Jacobians.

Parameters

- **circuits** (*list[.tape.QuantumTape]*) – circuits to execute on the device
- **method** (*str*) – the device method to call to compute the Jacobian of a single circuit

- `**kwargs` – keyword argument to pass when calling `method`

Returns
Tuple containing list of measured value(s) and list of Jacobians. Returned Jacobians should be of shape `(output_shape, num_params)`.

Return type
tuple[list[array[float]], list[array[float]]]

`execution_context()`

The device execution context used during calls to `execute()`.

You can overwrite this function to return a context manager in case your quantum library requires that; all operations and method calls (including `apply()` and `expval()`) are then evaluated within the context of this context manager (see the source of `execute()` for more details).

`expand_fn`(*circuit*, *max_expansion=10*)

Method for expanding or decomposing an input circuit. Can be the default or a custom expansion method, see `Device.default_expand_fn()` and `Device.custom_expand()` for more details.

Parameters

- **circuit** (*.QuantumTape*) – the circuit to expand.
- **max_expansion** (*int*) – The number of times the circuit should be expanded. Expansion occurs when an operation or measurement is not supported, and results in a gate decomposition. If any operations in the decomposition remain unsupported by the device, another expansion occurs.

Returns
The expanded/decomposed circuit, such that the device will natively support all operations.

Return type
.QuantumTape

`expval`(*observable*, *shot_range=None*, *bin_size=None*)

Returns the expectation value of observable on specified wires.

Note: all arguments accept _lists_, which indicate a tensor product of observables.

Parameters

- **observable** (*str or list[str]*) – name of the observable(s)
- **wires** (*Wires*) – wires the observable(s) are to be measured on
- **par** (*tuple or list[tuple]]*) – parameters for the observable(s)

Returns
expectation value $A = \psi A\psi$

Return type
float

`static generate_basis_states`(*num_wires*, *dtype=<class 'numpy.uint32'>*)

Generates basis states in binary representation according to the number of wires specified.

The states_to_binary method creates basis states faster (for larger systems at times over x25 times faster) than the approach using `itertools.product`, at the expense of using slightly more memory.

Due to the large size of the integer arrays for more than 32 bits, memory allocation errors may arise in the states_to_binary method. Hence we constraint the dtype of the array to represent unsigned integers on 32 bits. Due to this constraint, an overflow occurs for 32 or more wires, therefore this approach is used only for fewer wires.

For smaller number of wires speed is comparable to the next approach (using `itertools.product`), hence we resort to that one for testing purposes.

Parameters

- **num_wires** (*int*) – the number wires
- **dtype=np.uint32** (*type*) – the data type of the arrays to use

Returns
the sampled basis states

Return type
array[int]

generate_samples()

Returns the computational basis samples generated for all wires.

Note that PennyLane uses the convention $|q_0, q_1, \dots, q_{N-1}\rangle$ where q_0 is the most significant bit.

> **Warning:** This method should be overwritten on devices that generate their own computational basis samples, with the resulting computational basis samples stored as `self._samples`.

Returns
array of samples in the shape `(dev.shots, dev.num_wires)`

Return type
array[complex]

gradients(*circuits*, *method='jacobian'*, ***kwargs*)

Return the gradients of a batch of quantum circuits on the device.

The gradient method `method` is called sequentially for each circuit, and the corresponding Jacobians are collected in a list.

For plugin developers: This method should be overwritten if the device can efficiently compute the gradient of multiple circuits on a backend, for example using parallel and/or asynchronous executions.

Parameters

- **circuits** (*list[.tape.QuantumTape]*) – circuits to execute on the device
- **method** (*str*) – the device method to call to compute the Jacobian of a single circuit
- ****kwargs** – keyword argument to pass when calling `method`

Returns
List of Jacobians. Returned Jacobians should be of shape `(output_shape, num_params)`.

Return type
list[array[float]]

map_wires(*wires*)

Map the wire labels of wires using this device's wire map.

Parameters
wires (*Wires*) – wires whose labels we want to map to the device's internal labelling scheme

Returns
wires with new labels

Return type
Wires

`marginal_prob`(*prob*, *wires=None*)

Return the marginal probability of the computational basis states by summing the probabiliites on the non-specified wires.

If no wires are specified, then all the basis states representable by the device are considered and no marginalization takes place.

Note: If the provided wires are not in the order as they appear on the device, the returned marginal probabilities take this permutation into account.

For example, if the addressable wires on this device are `Wires([0, 1, 2])` and this function gets passed `wires=[2, 0]`, then the returned marginal probability vector will take this 'reversal' of the two wires into account:

$$\mathbb{P}^{(2,0)} = [|00\rangle, |10\rangle, |01\rangle, |11\rangle]$$

Parameters

- **prob** – The probabilities to return the marginal probabilities for
- **wires** (*Iterable[Number, str], Number, str, Wires*) – wires to return marginal probabilities for. Wires not provided are traced out of the system.

Returns
array of the resulting marginal probabilities.

Return type
array[float]

`mutual_info`(*wires0*, *wires1*, *log_base*)

Returns the mutual information prior to measurement:

$$I(A, B) = S(\rho^A) + S(\rho^B) - S(\rho^{AB})$$

where S is the von Neumann entropy.

Parameters

- **wires0** (*Wires*) – wires of the first subsystem
- **wires1** (*Wires*) – wires of the second subsystem
- **log_base** (*float*) – base to use in the logarithm

Returns
the mutual information

Return type
float

`order_wires`(*subset_wires*)

Given some subset of device wires return a Wires object with the same wires; sorted according to the device wire map.

Parameters
subset_wires (*Wires*) – The subset of device wires (in any order).

Raises
`ValueError` – Could not find some or all subset wires subset_wires in device wires device_wires.

Returns
a new Wires object containing the re-ordered wires set

Return type
ordered_wires (Wires)

`post_apply()`
Called during `execute()` after the individual operations have been executed.

`post_measure()`
Called during `execute()` after the individual observables have been measured.

`pre_apply()`
Called during `execute()` before the individual operations are executed.

`pre_measure()`
Called during `execute()` before the individual observables are measured.

`probability`(*wires=None*, *shot_range=None*, *bin_size=None*)
Return either the analytic probability or estimated probability of each computational basis state.

Devices that require a finite number of shots always return the estimated probability.

Parameters
wires (*Iterable[Number, str], Number, str, Wires*) – wires to return marginal probabilities for. Wires not provided are traced out of the system.

Returns
list of the probabilities

Return type
array[float]

`reset()`
Reset the backend state.

After the reset, the backend should be as if it was just constructed. Most importantly the quantum state is reset to its initial value.

`sample`(*observable*, *shot_range=None*, *bin_size=None*, *counts=False*)
Return samples of an observable.

Parameters

- **observable** (*Observable*) – the observable to sample
- **shot_range** (*tuple[int]*) – 2-tuple of integers specifying the range of samples to use. If not specified, all samples are used.
- **bin_size** (*int*) – Divides the shot range into bins of size `bin_size`, and returns the measurement statistic separately over each bin. If not provided, the entire shot range is treated as a single bin.
- **counts** (*bool*) – whether counts (`True`) or raw samples (`False`) should be returned

Raises
`EigvalsUndefinedError` – if no information is available about the eigenvalues of the observable

Returns
samples in an array of dimension `(shots,)` or counts

Return type
Union[array[float], dict, list[dict]]

`sample_basis_states`(*number_of_states*, *state_probability*)

Sample from the computational basis states based on the state probability.

This is an auxiliary method to the generate_samples method.

Parameters

- **number_of_states** (*int*) – the number of basis states to sample from
- **state_probability** (*array[float]*) – the computational basis probability vector

Returns
the sampled basis states

Return type
array[int]

`shadow_expval`(*obs*, *circuit*)

Compute expectation values using classical shadows in a differentiable manner.

Please refer to `shadow_expval()` for detailed documentation.

Parameters

- **obs** (*ClassicalShadowMP*) – The classical shadow expectation value measurement process
- **circuit** (*QuantumTape*) – The quantum tape that is being executed

Returns
expectation value estimate.

Return type
float

`shot_vec_statistics`(*circuit: QuantumTape*)

Process measurement results from circuit execution using a device with a shot vector and return statistics.

This is an auxiliary method of execute and uses statistics.

When using shot vectors, measurement results for each item of the shot vector are contained in a tuple.

Parameters
circuit (*QuantumTape*) – circuit to execute on the device

Raises
QuantumFunctionError – if the value of `return_type` is not supported

Returns
stastics for each shot item from the shot vector

Return type
tuple

`static states_to_binary`(*samples*, *num_wires*, *dtype=<class 'numpy.int64'>*)

Convert basis states from base 10 to binary representation.

This is an auxiliary method to the generate_samples method.

Parameters

- **samples** (*array[int]*) – samples of basis states in base 10 representation
- **num_wires** (*int*) – the number of qubits
- **dtype** (*type*) – Type of the internal integer array to be used. Can be important to specify for large systems for memory allocation purposes.

Returns
basis states in binary representation

Return type
array[int]

`statistics`(*braket_result: GateModelQuantumTaskResult*, *measurements: Sequence[MeasurementProcess]*) → list[float]

Processes measurement results from a Braket task result and returns statistics.

Parameters

- **braket_result** (*GateModelQuantumTaskResult*) – the Braket task result
- **measurements** (*Sequence[MeasurementProcess]*) – the list of measurements

Raises
QuantumFunctionError – if the value of `return_type` is not supported.

Returns
the corresponding statistics

Return type
list[float]

`supports_observable`(*observable*)

Checks if an observable is supported by this device. Raises a ValueError,
if not a subclass or string of an Observable was passed.

Parameters
observable (*type or str*) – observable to be checked

Raises
ValueError – if *observable* is not a `Observable` class or string

Returns
`True` iff supplied observable is supported

Return type
bool

`supports_operation`(*operation*)

Checks if an operation is supported by this device.

Parameters
operation (*type or str*) – operation to be checked

Raises
ValueError – if *operation* is not a `Operation` class or string

Returns
`True` if supplied operation is supported

Return type
bool

var(*observable*, *shot_range=None*, *bin_size=None*)

Returns the variance of observable on specified wires.

Note: all arguments support _lists_, which indicate a tensor product of observables.

Parameters

- **observable** (*str or list[str]*) – name of the observable(s)
- **wires** (*Wires*) – wires the observable(s) is to be measured on
- **par** (*tuple or list[tuple]]*) – parameters for the observable(s)

Raises
NotImplementedError – if the device does not support variance computation

Returns
variance $\mathrm{var}(A) = \psi A^2 \psi - \psi A \psi^2$

Return type
float

vn_entropy(*wires*, *log_base*)

Returns the Von Neumann entropy prior to measurement.

$$S(\rho) = -\mathrm{Tr}(\rho \log(\rho))$$

Parameters

- **wires** (*Wires*) – Wires of the considered subsystem.
- **log_base** (*float*) – Base for the logarithm, default is None the natural logarithm is used in this case.

Returns
returns the Von Neumann entropy

Return type
float

CPhaseShift00

class CPhaseShift00(*phi*, *wires*)

Bases: `Operation`

Controlled phase shift gate phasing the $|00\rangle$ state.

$$\mathtt{CPhaseShift00}(\phi) = \begin{bmatrix} e^{i\phi} & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$

Details:

- Number of wires: 2
- Number of parameters: 1
- Gradient recipe:

$$\frac{d}{d\phi}\texttt{CPhaseShift00}(\phi) = \frac{1}{2}\left[\texttt{CPhaseShift00}(\phi + \pi/2) - \texttt{CPhaseShift00}(\phi - \pi/2)\right]$$

Parameters

- **phi** (*float*) – the controlled phase angle
- **wires** (*int*) – the subsystem the gate acts on
- **id** (*str, optional*) – String representing the operation. Default: None

arithmetic_depth	Arithmetic depth of the operator.
basis	The basis of an operation, or for controlled gates, of the target operation.
batch_size	Batch size of the operator if it is used with broadcasted parameters.
control_wires	Control wires of the operator.
grad_method	
grad_recipe	Gradient recipe for the parameter-shift method.
has_adjoint	
has_decomposition	
has_diagonalizing_gates	
has_generator	
has_matrix	
hash	Integer hash that uniquely represents the operator.
hyperparameters	Dictionary of non-trainable variables that this operation depends on.
id	Custom string to label a specific operator instance.
is_hermitian	This property determines if an operator is hermitian.
name	String for the name of the operator.
ndim_params	Number of dimensions per trainable parameter of the operator.
num_params	
num_wires	Number of wires the operator acts on.
parameter_frequencies	
parameters	Trainable parameters that the operator depends on.
pauli_rep	A `PauliSentence` representation of the Operator, or `None` if it doesn't have one.
wires	Wires that the operator acts on.

arithmetic_depth

Arithmetic depth of the operator.

basis

The basis of an operation, or for controlled gates, of the target operation. If not `None`, should take a value of `"X"`, `"Y"`, or `"Z"`.

For example, `X` and `CNOT` have `basis = "X"`, whereas `ControlledPhaseShift` and `RZ` have `basis = "Z"`.

Type
str or None

batch_size

Batch size of the operator if it is used with broadcasted parameters.

The `batch_size` is determined based on `ndim_params` and the provided parameters for the operator. If (some of) the latter have an additional dimension, and this dimension has the same size for all parameters, its size is the batch size of the operator. If no parameter has an additional dimension, the batch size is `None`.

Returns
Size of the parameter broadcasting dimension if present, else `None`.

Return type
int or None

control_wires

Control wires of the operator.

For operations that are not controlled, this is an empty `Wires` object of length `0`.

Returns
The control wires of the operation.

Return type
Wires

grad_method = 'A'

grad_recipe = None

Gradient recipe for the parameter-shift method.

This is a tuple with one nested list per operation parameter. For parameter ϕ_k, the nested list contains elements of the form $[c_i, a_i, s_i]$ where i is the index of the term, resulting in a gradient recipe of

$$\frac{\partial}{\partial\phi_k}f = \sum_i c_i f(a_i\phi_k + s_i).$$

If `None`, the default gradient recipe containing the two terms $[c_0, a_0, s_0] = [1/2, 1, \pi/2]$ and $[c_1, a_1, s_1] = [-1/2, 1, -\pi/2]$ is assumed for every parameter.

Type
tuple(Union(list[list[float]], None)) or None

has_adjoint = True

has_decomposition = True

has_diagonalizing_gates = False

has_generator = True

has_matrix = True

hash

Integer hash that uniquely represents the operator.

Type
int

hyperparameters

Dictionary of non-trainable variables that this operation depends on.

Type
dict

id

Custom string to label a specific operator instance.

is_hermitian

This property determines if an operator is hermitian.

name

String for the name of the operator.

ndim_params

Number of dimensions per trainable parameter of the operator.

By default, this property returns the numbers of dimensions of the parameters used for the operator creation. If the parameter sizes for an operator subclass are fixed, this property can be overwritten to return the fixed value.

Returns
Number of dimensions for each trainable parameter.

Return type
tuple

num_params = 1

num_wires = 2

Number of wires the operator acts on.

parameter_frequencies = [(1,)]

parameters

Trainable parameters that the operator depends on.

pauli_rep

A `PauliSentence` representation of the Operator, or `None` if it doesn't have one.

wires

Wires that the operator acts on.

Returns
wires

Return type
Wires

`adjoint`()	Create an operation that is the adjoint of this one.
`compute_decomposition`(phi, wires)	Representation of the operator as a product of other operators (static method).
`compute_diagonalizing_gates`(*params, wires, ...)	Sequence of gates that diagonalize the operator in the computational basis (static method).
`compute_eigvals`(*params, **hyperparams)	Eigenvalues of the operator in the computational basis (static method).
`compute_matrix`(phi)	Representation of the operator as a canonical matrix in the computational basis (static method).
`compute_sparse_matrix`(*params, **hyperparams)	Representation of the operator as a sparse matrix in the computational basis (static method).
`decomposition`()	Representation of the operator as a product of other operators.
`diagonalizing_gates`()	Sequence of gates that diagonalize the operator in the computational basis.
`eigvals`()	Eigenvalues of the operator in the computational basis.
`expand`()	Returns a tape that contains the decomposition of the operator.
`generator`()	Generator of an operator that is in single-parameter-form.
`label`([decimals, base_label, cache])	A customizable string representation of the operator.
`map_wires`(wire_map)	Returns a copy of the current operator with its wires changed according to the given wire map.
`matrix`([wire_order])	Representation of the operator as a matrix in the computational basis.
`pow`(z)	A list of new operators equal to this one raised to the given power.
`queue`([context])	Append the operator to the Operator queue.
`simplify`()	Reduce the depth of nested operators to the minimum.
`single_qubit_rot_angles`()	The parameters required to implement a single-qubit gate as an equivalent `Rot` gate, up to a global phase.
`sparse_matrix`([wire_order])	Representation of the operator as a sparse matrix in the computational basis.
`terms`()	Representation of the operator as a linear combination of other operators.
`validate_subspace`(subspace)	Validate the subspace for qutrit operations.

adjoint()

Create an operation that is the adjoint of this one.

Adjointed operations are the conjugated and transposed version of the original operation. Adjointed ops are equivalent to the inverted operation for unitary gates.

Returns
The adjointed operation.

static compute_decomposition(*phi*, *wires*)

Representation of the operator as a product of other operators (static method).

$$O = O_1 O_2 \dots O_n.$$

Note: Operations making up the decomposition should be queued within the `compute_decomposition`

method.

See also:

`decomposition()`.

Parameters

- **`*params`** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **`wires`** (*Iterable[Any], Wires*) – wires that the operator acts on
- **`**hyperparams`** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
decomposition of the operator

Return type
list[Operator]

static compute_diagonalizing_gates(**params, wires, **hyperparams*)

Sequence of gates that diagonalize the operator in the computational basis (static method).

Given the eigendecomposition $O = U\Sigma U^{\dagger}$ where Σ is a diagonal matrix containing the eigenvalues, the sequence of diagonalizing gates implements the unitary $U^{\dagger}$.

The diagonalizing gates rotate the state into the eigenbasis of the operator.

See also:

`diagonalizing_gates()`.

Parameters

- **`params`** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **`wires`** (*Iterable[Any], Wires*) – wires that the operator acts on
- **`hyperparams`** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
list of diagonalizing gates

Return type
list[.Operator]

static compute_eigvals(**params, **hyperparams*)

Eigenvalues of the operator in the computational basis (static method).

If *diagonalizing_gates* are specified and implement a unitary $U^{\dagger}$, the operator can be reconstructed as

$$O = U\Sigma U^{\dagger},$$

where Σ is the diagonal matrix containing the eigenvalues.

Otherwise, no particular order for the eigenvalues is guaranteed.

See also:

Operator.eigvals() and qml.eigvals()

Parameters

- ***params** (*list*) – trainable parameters of the operator, as stored in the parameters attribute
- ****hyperparams** (*dict*) – non-trainable hyperparameters of the operator, as stored in the hyperparameters attribute

Returns
eigenvalues

Return type
tensor_like

static compute_matrix(*phi*)

Representation of the operator as a canonical matrix in the computational basis (static method).

The canonical matrix is the textbook matrix representation that does not consider wires. Implicitly, this assumes that the wires of the operator correspond to the global wire order.

See also:

Operator.matrix() and qml.matrix()

Parameters

- ***params** (*list*) – trainable parameters of the operator, as stored in the parameters attribute
- ****hyperparams** (*dict*) – non-trainable hyperparameters of the operator, as stored in the hyperparameters attribute

Returns
matrix representation

Return type
tensor_like

static compute_sparse_matrix(**params*, ***hyperparams*)

Representation of the operator as a sparse matrix in the computational basis (static method).

The canonical matrix is the textbook matrix representation that does not consider wires. Implicitly, this assumes that the wires of the operator correspond to the global wire order.

See also:

sparse_matrix()

Parameters

- ***params** (*list*) – trainable parameters of the operator, as stored in the parameters attribute
- ****hyperparams** (*dict*) – non-trainable hyperparameters of the operator, as stored in the hyperparameters attribute

Returns
sparse matrix representation

Return type
scipy.sparse._csr.csr_matrix

`decomposition()`

Representation of the operator as a product of other operators.

$$O = O_1 O_2 \dots O_n$$

A `DecompositionUndefinedError` is raised if no representation by decomposition is defined.

See also:

`compute_decomposition()`.

Returns
decomposition of the operator

Return type
list[Operator]

`diagonalizing_gates()`

Sequence of gates that diagonalize the operator in the computational basis.

Given the eigendecomposition $O = U\Sigma U^\dagger$ where Σ is a diagonal matrix containing the eigenvalues, the sequence of diagonalizing gates implements the unitary $U^\dagger$.

The diagonalizing gates rotate the state into the eigenbasis of the operator.

A `DiagGatesUndefinedError` is raised if no representation by decomposition is defined.

See also:

`compute_diagonalizing_gates()`.

Returns
a list of operators

Return type
list[.Operator] or None

`eigvals()`

Eigenvalues of the operator in the computational basis.

If *`diagonalizing_gates`* are specified and implement a unitary $U^\dagger$, the operator can be reconstructed as

$$O = U\Sigma U^\dagger,$$

where Σ is the diagonal matrix containing the eigenvalues.

Otherwise, no particular order for the eigenvalues is guaranteed.

Note: When eigenvalues are not explicitly defined, they are computed automatically from the matrix representation. Currently, this computation is *not* differentiable.

A `EigvalsUndefinedError` is raised if the eigenvalues have not been defined and cannot be inferred from the matrix representation.

See also:

`compute_eigvals()`

Returns
eigenvalues

Return type
tensor_like

expand()

Returns a tape that contains the decomposition of the operator.

Returns
quantum tape

Return type
.QuantumTape

generator()

Generator of an operator that is in single-parameter-form.

For example, for operator

$$U(\phi) = e^{i\phi(0.5Y + Z\otimes X)}$$

we get the generator

```
>>> U.generator()
  (0.5) [Y0]
+ (1.0) [Z0 X1]
```

The generator may also be provided in the form of a dense or sparse Hamiltonian (using `Hermitian` and `SparseHamiltonian` respectively).

The default value to return is `None`, indicating that the operation has no defined generator.

label(*decimals=None*, *base_label=None*, *cache=None*)

A customizable string representation of the operator.

Parameters

- **decimals=None** (*int*) – If `None`, no parameters are included. Else, specifies how to round the parameters.
- **base_label=None** (*str*) – overwrite the non-parameter component of the label
- **cache=None** (*dict*) – dictionary that carries information between label calls in the same drawing

Returns
label to use in drawings

Return type
str

Example:

```
>>> op = qml.RX(1.23456, wires=0)
>>> op.label()
"RX"
>>> op.label(base_label="my_label")
"my_label"
>>> op = qml.RX(1.23456, wires=0, id="test_data")
```

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```
>>> op.label()
"RX("test_data")"
>>> op.label(decimals=2)
"RX\n(1.23,"test_data")"
>>> op.label(base_label="my_label")
"my_label("test_data")"
>>> op.label(decimals=2, base_label="my_label")
"my_label\n(1.23,"test_data")"
```

If the operation has a matrix-valued parameter and a cache dictionary is provided, unique matrices will be cached in the `'matrices'` key list. The label will contain the index of the matrix in the `'matrices'` list.

```
>>> op2 = qml.QubitUnitary(np.eye(2), wires=0)
>>> cache = {'matrices': []}
>>> op2.label(cache=cache)
'U(M0)'
>>> cache['matrices']
[tensor([[1., 0.],
 [0., 1.]], requires_grad=True)]
>>> op3 = qml.QubitUnitary(np.eye(4), wires=(0,1))
>>> op3.label(cache=cache)
'U(M1)'
>>> cache['matrices']
[tensor([[1., 0.],
        [0., 1.]], requires_grad=True),
tensor([[1., 0., 0., 0.],
        [0., 1., 0., 0.],
        [0., 0., 1., 0.],
        [0., 0., 0., 1.]], requires_grad=True)]
```

map_wires(*wire_map: dict*)

Returns a copy of the current operator with its wires changed according to the given wire map.

Parameters
: **wire_map** (*dict*) – dictionary containing the old wires as keys and the new wires as values

Returns
: new operator

Return type
: .Operator

matrix(*wire_order=None*)

Representation of the operator as a matrix in the computational basis.

If `wire_order` is provided, the numerical representation considers the position of the operator's wires in the global wire order. Otherwise, the wire order defaults to the operator's wires.

If the matrix depends on trainable parameters, the result will be cast in the same autodifferentiation framework as the parameters.

A `MatrixUndefinedError` is raised if the matrix representation has not been defined.

See also:

`compute_matrix()`

Parameters
`wire_order` (*Iterable*) – global wire order, must contain all wire labels from the operator's wires

Returns
matrix representation

Return type
tensor_like

pow(*z*) → List[Operator]

A list of new operators equal to this one raised to the given power.

Parameters
z (*float*) – exponent for the operator

Returns
list[Operator]

queue(*context=<class 'pennylane.queuing.QueuingManager'>*)

Append the operator to the Operator queue.

simplify() → Operator

Reduce the depth of nested operators to the minimum.

Returns
simplified operator

Return type
.Operator

single_qubit_rot_angles()

The parameters required to implement a single-qubit gate as an equivalent `Rot` gate, up to a global phase.

Returns
A list of values $[\phi, \theta, \omega]$ such that $RZ(\omega)RY(\theta)RZ(\phi)$ is equivalent to the original operation.

Return type
tuple[float, float, float]

sparse_matrix(*wire_order=None*)

Representation of the operator as a sparse matrix in the computational basis.

If `wire_order` is provided, the numerical representation considers the position of the operator's wires in the global wire order. Otherwise, the wire order defaults to the operator's wires.

A `SparseMatrixUndefinedError` is raised if the sparse matrix representation has not been defined.

See also:

`compute_sparse_matrix()`

Parameters
`wire_order` (*Iterable*) – global wire order, must contain all wire labels from the operator's wires

Returns
sparse matrix representation

Return type
scipy.sparse._csr.csr_matrix

terms()

Representation of the operator as a linear combination of other operators.

$$O = \sum_i c_i O_i$$

A `TermsUndefinedError` is raised if no representation by terms is defined.

Returns
list of coefficients c_i and list of operations O_i

Return type
tuple[list[tensor_like or float], list[.Operation]]

static **validate_subspace**(*subspace*)

Validate the subspace for qutrit operations.

This method determines whether a given subspace for qutrit operations is defined correctly or not. If not, a *ValueError* is thrown.

Parameters
subspace (*tuple[int]*) – Subspace to check for correctness

CPhaseShift01

class **CPhaseShift01**(*phi*, *wires*)

Bases: `Operation`

Controlled phase shift gate phasing the $|01\rangle$ state.

$$\mathtt{CPhaseShift01}(\phi) = \begin{bmatrix}1 & 0 & 0 & 0\\ 0 & e^{i\phi} & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}.$$

Details:

- Number of wires: 2
- Number of parameters: 1
- Gradient recipe:

$$\frac{d}{d\phi}\mathtt{CPhaseShift01}(\phi) = \frac{1}{2}\left[\mathtt{CPhaseShift01}(\phi + \pi/2) - \mathtt{CPhaseShift01}(\phi - \pi/2)\right]$$

Parameters

- **phi** (*float*) – the controlled phase angle
- **wires** (*int*) – the subsystem the gate acts on
- **id** (*str or None*) – String representing the operation (optional)

arithmetic_depth	Arithmetic depth of the operator.
basis	The basis of an operation, or for controlled gates, of the target operation.
batch_size	Batch size of the operator if it is used with broadcasted parameters.
control_wires	Control wires of the operator.
grad_method	
grad_recipe	Gradient recipe for the parameter-shift method.
has_adjoint	
has_decomposition	
has_diagonalizing_gates	
has_generator	
has_matrix	
hash	Integer hash that uniquely represents the operator.
hyperparameters	Dictionary of non-trainable variables that this operation depends on.
id	Custom string to label a specific operator instance.
is_hermitian	This property determines if an operator is hermitian.
name	String for the name of the operator.
ndim_params	Number of dimensions per trainable parameter of the operator.
num_params	
num_wires	Number of wires the operator acts on.
parameter_frequencies	
parameters	Trainable parameters that the operator depends on.
pauli_rep	A `PauliSentence` representation of the Operator, or `None` if it doesn't have one.
wires	Wires that the operator acts on.

arithmetic_depth

Arithmetic depth of the operator.

basis

The basis of an operation, or for controlled gates, of the target operation. If not `None`, should take a value of `"X"`, `"Y"`, or `"Z"`.

For example, `X` and `CNOT` have `basis = "X"`, whereas `ControlledPhaseShift` and `RZ` have `basis = "Z"`.

Type
str or None

batch_size

Batch size of the operator if it is used with broadcasted parameters.

The `batch_size` is determined based on `ndim_params` and the provided parameters for the operator. If (some of) the latter have an additional dimension, and this dimension has the same size for all parameters, its size is the batch size of the operator. If no parameter has an additional dimension, the batch size is `None`.

Returns
Size of the parameter broadcasting dimension if present, else `None`.

Return type
int or None

control_wires

Control wires of the operator.

For operations that are not controlled, this is an empty `Wires` object of length `0`.

Returns
The control wires of the operation.

Return type
Wires

grad_method = 'A'

grad_recipe = None

Gradient recipe for the parameter-shift method.

This is a tuple with one nested list per operation parameter. For parameter ϕ_k, the nested list contains elements of the form $[c_i, a_i, s_i]$ where i is the index of the term, resulting in a gradient recipe of

$$\frac{\partial}{\partial\phi_k}f = \sum_i c_i f(a_i\phi_k + s_i).$$

If `None`, the default gradient recipe containing the two terms $[c_0, a_0, s_0] = [1/2, 1, \pi/2]$ and $[c_1, a_1, s_1] = [-1/2, 1, -\pi/2]$ is assumed for every parameter.

Type
tuple(Union(list[list[float]], None)) or None

has_adjoint = True

has_decomposition = True

has_diagonalizing_gates = False

has_generator = True

has_matrix = True

hash

Integer hash that uniquely represents the operator.

Type
int

hyperparameters

Dictionary of non-trainable variables that this operation depends on.

Type
dict

id

Custom string to label a specific operator instance.

`is_hermitian`

This property determines if an operator is hermitian.

`name`

String for the name of the operator.

`ndim_params`

Number of dimensions per trainable parameter of the operator.

By default, this property returns the numbers of dimensions of the parameters used for the operator creation. If the parameter sizes for an operator subclass are fixed, this property can be overwritten to return the fixed value.

Returns

Number of dimensions for each trainable parameter.

Return type

tuple

`num_params = 1`

`num_wires = 2`

Number of wires the operator acts on.

`parameter_frequencies = [(1,)]`

`parameters`

Trainable parameters that the operator depends on.

`pauli_rep`

A `PauliSentence` representation of the Operator, or `None` if it doesn't have one.

`wires`

Wires that the operator acts on.

Returns

wires

Return type

Wires

adjoint()	Create an operation that is the adjoint of this one.
compute_decomposition(phi, wires)	Representation of the operator as a product of other operators (static method).
compute_diagonalizing_gates(*params, wires, ...)	Sequence of gates that diagonalize the operator in the computational basis (static method).
compute_eigvals(*params, **hyperparams)	Eigenvalues of the operator in the computational basis (static method).
compute_matrix(phi)	Representation of the operator as a canonical matrix in the computational basis (static method).
compute_sparse_matrix(*params, **hyperparams)	Representation of the operator as a sparse matrix in the computational basis (static method).
decomposition()	Representation of the operator as a product of other operators.
diagonalizing_gates()	Sequence of gates that diagonalize the operator in the computational basis.
eigvals()	Eigenvalues of the operator in the computational basis.
expand()	Returns a tape that contains the decomposition of the operator.
generator()	Generator of an operator that is in single-parameter-form.
label([decimals, base_label, cache])	A customizable string representation of the operator.
map_wires(wire_map)	Returns a copy of the current operator with its wires changed according to the given wire map.
matrix([wire_order])	Representation of the operator as a matrix in the computational basis.
pow(z)	A list of new operators equal to this one raised to the given power.
queue([context])	Append the operator to the Operator queue.
simplify()	Reduce the depth of nested operators to the minimum.
single_qubit_rot_angles()	The parameters required to implement a single-qubit gate as an equivalent `Rot` gate, up to a global phase.
sparse_matrix([wire_order])	Representation of the operator as a sparse matrix in the computational basis.
terms()	Representation of the operator as a linear combination of other operators.
validate_subspace(subspace)	Validate the subspace for qutrit operations.

adjoint()

Create an operation that is the adjoint of this one.

Adjointed operations are the conjugated and transposed version of the original operation. Adjointed ops are equivalent to the inverted operation for unitary gates.

Returns
The adjointed operation.

static compute_decomposition(*phi*, *wires*)

Representation of the operator as a product of other operators (static method).

$$O = O_1 O_2 \dots O_n.$$

Note: Operations making up the decomposition should be queued within the `compute_decomposition`

method.

See also:

`decomposition()`.

Parameters

- ***params** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **wires** (*Iterable[Any], Wires*) – wires that the operator acts on
- ****hyperparams** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
decomposition of the operator

Return type
list[Operator]

static compute_diagonalizing_gates(**params*, *wires*, ***hyperparams*)

Sequence of gates that diagonalize the operator in the computational basis (static method).

Given the eigendecomposition $O = U\Sigma U^{\dagger}$ where Σ is a diagonal matrix containing the eigenvalues, the sequence of diagonalizing gates implements the unitary $U^{\dagger}$.

The diagonalizing gates rotate the state into the eigenbasis of the operator.

See also:

`diagonalizing_gates()`.

Parameters

- **params** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **wires** (*Iterable[Any], Wires*) – wires that the operator acts on
- **hyperparams** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
list of diagonalizing gates

Return type
list[.Operator]

static compute_eigvals(**params*, ***hyperparams*)

Eigenvalues of the operator in the computational basis (static method).

If `diagonalizing_gates` are specified and implement a unitary $U^{\dagger}$, the operator can be reconstructed as

$$O = U\Sigma U^{\dagger},$$

where Σ is the diagonal matrix containing the eigenvalues.

Otherwise, no particular order for the eigenvalues is guaranteed.

See also:

Operator.eigvals() and `qml.eigvals()`

Parameters

- ***params** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- ****hyperparams** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
eigenvalues

Return type
tensor_like

`static compute_matrix(phi)`

Representation of the operator as a canonical matrix in the computational basis (static method).

The canonical matrix is the textbook matrix representation that does not consider wires. Implicitly, this assumes that the wires of the operator correspond to the global wire order.

See also:

`Operator.matrix()` and `qml.matrix()`

Parameters

- ***params** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- ****hyperparams** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
matrix representation

Return type
tensor_like

`static compute_sparse_matrix(*params, **hyperparams)`

Representation of the operator as a sparse matrix in the computational basis (static method).

The canonical matrix is the textbook matrix representation that does not consider wires. Implicitly, this assumes that the wires of the operator correspond to the global wire order.

See also:

`sparse_matrix()`

Parameters

- ***params** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- ****hyperparams** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
sparse matrix representation

Return type
scipy.sparse._csr.csr_matrix

decomposition()

Representation of the operator as a product of other operators.

$$O = O_1 O_2 \dots O_n$$

A `DecompositionUndefinedError` is raised if no representation by decomposition is defined.

See also:

`compute_decomposition()`.

Returns
decomposition of the operator

Return type
list[Operator]

diagonalizing_gates()

Sequence of gates that diagonalize the operator in the computational basis.

Given the eigendecomposition $O = U\Sigma U^{\dagger}$ where Σ is a diagonal matrix containing the eigenvalues, the sequence of diagonalizing gates implements the unitary $U^{\dagger}$.

The diagonalizing gates rotate the state into the eigenbasis of the operator.

A `DiagGatesUndefinedError` is raised if no representation by decomposition is defined.

See also:

`compute_diagonalizing_gates()`.

Returns
a list of operators

Return type
list[.Operator] or None

eigvals()

Eigenvalues of the operator in the computational basis.

If *diagonalizing_gates* are specified and implement a unitary $U^{\dagger}$, the operator can be reconstructed as

$$O = U\Sigma U^{\dagger},$$

where Σ is the diagonal matrix containing the eigenvalues.

Otherwise, no particular order for the eigenvalues is guaranteed.

Note: When eigenvalues are not explicitly defined, they are computed automatically from the matrix representation. Currently, this computation is *not* differentiable.

A `EigvalsUndefinedError` is raised if the eigenvalues have not been defined and cannot be inferred from the matrix representation.

See also:

`compute_eigvals()`

Returns
eigenvalues

Return type
tensor_like

`expand()`

Returns a tape that contains the decomposition of the operator.

Returns
quantum tape

Return type
.QuantumTape

`generator()`

Generator of an operator that is in single-parameter-form.

For example, for operator

$$U(\phi) = e^{i\phi(0.5Y + Z\otimes X)}$$

we get the generator

```
>>> U.generator()
  (0.5) [Y0]
+ (1.0) [Z0 X1]
```

The generator may also be provided in the form of a dense or sparse Hamiltonian (using `Hermitian` and `SparseHamiltonian` respectively).

The default value to return is `None`, indicating that the operation has no defined generator.

`label`(*decimals=None*, *base_label=None*, *cache=None*)

A customizable string representation of the operator.

Parameters

- **decimals=None** (*int*) – If `None`, no parameters are included. Else, specifies how to round the parameters.
- **base_label=None** (*str*) – overwrite the non-parameter component of the label
- **cache=None** (*dict*) – dictionary that carries information between label calls in the same drawing

Returns
label to use in drawings

Return type
str

Example:

```
>>> op = qml.RX(1.23456, wires=0)
>>> op.label()
"RX"
>>> op.label(base_label="my_label")
"my_label"
>>> op = qml.RX(1.23456, wires=0, id="test_data")
```

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```
>>> op.label()
"RX("test_data")"
>>> op.label(decimals=2)
"RX\n(1.23,"test_data")"
>>> op.label(base_label="my_label")
"my_label("test_data")"
>>> op.label(decimals=2, base_label="my_label")
"my_label\n(1.23,"test_data")"
```

If the operation has a matrix-valued parameter and a cache dictionary is provided, unique matrices will be cached in the `'matrices'` key list. The label will contain the index of the matrix in the `'matrices'` list.

```
>>> op2 = qml.QubitUnitary(np.eye(2), wires=0)
>>> cache = {'matrices': []}
>>> op2.label(cache=cache)
'U(M0)'
>>> cache['matrices']
[tensor([[1., 0.],
 [0., 1.]], requires_grad=True)]
>>> op3 = qml.QubitUnitary(np.eye(4), wires=(0,1))
>>> op3.label(cache=cache)
'U(M1)'
>>> cache['matrices']
[tensor([[1., 0.],
        [0., 1.]], requires_grad=True),
tensor([[1., 0., 0., 0.],
        [0., 1., 0., 0.],
        [0., 0., 1., 0.],
        [0., 0., 0., 1.]], requires_grad=True)]
```

map_wires(*wire_map: dict*)

Returns a copy of the current operator with its wires changed according to the given wire map.

Parameters

wire_map (*dict*) – dictionary containing the old wires as keys and the new wires as values

Returns

new operator

Return type

.Operator

matrix(*wire_order=None*)

Representation of the operator as a matrix in the computational basis.

If `wire_order` is provided, the numerical representation considers the position of the operator's wires in the global wire order. Otherwise, the wire order defaults to the operator's wires.

If the matrix depends on trainable parameters, the result will be cast in the same autodifferentiation framework as the parameters.

A `MatrixUndefinedError` is raised if the matrix representation has not been defined.

See also:

`compute_matrix()`

Parameters
wire_order (*Iterable*) – global wire order, must contain all wire labels from the operator's wires

Returns
matrix representation

Return type
tensor_like

pow(z) → List[Operator]

A list of new operators equal to this one raised to the given power.

Parameters
z (*float*) – exponent for the operator

Returns
list[Operator]

queue(*context=<class 'pennylane.queuing.QueuingManager'>*)

Append the operator to the Operator queue.

simplify() → Operator

Reduce the depth of nested operators to the minimum.

Returns
simplified operator

Return type
.Operator

single_qubit_rot_angles()

The parameters required to implement a single-qubit gate as an equivalent `Rot` gate, up to a global phase.

Returns
A list of values $[\phi, \theta, \omega]$ such that $RZ(\omega)RY(\theta)RZ(\phi)$ is equivalent to the original operation.

Return type
tuple[float, float, float]

sparse_matrix(*wire_order=None*)

Representation of the operator as a sparse matrix in the computational basis.

If `wire_order` is provided, the numerical representation considers the position of the operator's wires in the global wire order. Otherwise, the wire order defaults to the operator's wires.

A `SparseMatrixUndefinedError` is raised if the sparse matrix representation has not been defined.

See also:

`compute_sparse_matrix()`

Parameters
wire_order (*Iterable*) – global wire order, must contain all wire labels from the operator's wires

Returns
sparse matrix representation

Return type
scipy.sparse._csr.csr_matrix

terms()

Representation of the operator as a linear combination of other operators.

$$O = \sum_i c_i O_i$$

A `TermsUndefinedError` is raised if no representation by terms is defined.

Returns
list of coefficients c_i and list of operations O_i

Return type
tuple[list[tensor_like or float], list[.Operation]]

static **validate_subspace**(*subspace*)

Validate the subspace for qutrit operations.

This method determines whether a given subspace for qutrit operations is defined correctly or not. If not, a *ValueError* is thrown.

Parameters
subspace (*tuple[int]*) – Subspace to check for correctness

CPhaseShift10

class **CPhaseShift10**(*phi*, *wires*)

Bases: `Operation`

Controlled phase shift gate phasing the $|10\rangle$ state.

$$\texttt{CPhaseShift10}(\phi) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & e^{i\phi} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$

Details:

- Number of wires: 2
- Number of parameters: 1
- Gradient recipe:

$$\frac{d}{d\phi}\texttt{CPhaseShift10}(\phi) = \frac{1}{2}\left[\texttt{CPhaseShift10}(\phi + \pi/2) - \texttt{CPhaseShift10}(\phi - \pi/2)\right]$$

Parameters

- **phi** (*float*) – the controlled phase angle
- **wires** (*int*) – the subsystem the gate acts on
- **id** (*str or None*) – String representing the operation (optional)

arithmetic_depth	Arithmetic depth of the operator.
basis	The basis of an operation, or for controlled gates, of the target operation.
batch_size	Batch size of the operator if it is used with broadcasted parameters.
control_wires	Control wires of the operator.
grad_method	
grad_recipe	Gradient recipe for the parameter-shift method.
has_adjoint	
has_decomposition	
has_diagonalizing_gates	
has_generator	
has_matrix	
hash	Integer hash that uniquely represents the operator.
hyperparameters	Dictionary of non-trainable variables that this operation depends on.
id	Custom string to label a specific operator instance.
is_hermitian	This property determines if an operator is hermitian.
name	String for the name of the operator.
ndim_params	Number of dimensions per trainable parameter of the operator.
num_params	
num_wires	Number of wires the operator acts on.
parameter_frequencies	
parameters	Trainable parameters that the operator depends on.
pauli_rep	A PauliSentence representation of the Operator, or None if it doesn't have one.
wires	Wires that the operator acts on.

arithmetic_depth

Arithmetic depth of the operator.

basis

The basis of an operation, or for controlled gates, of the target operation. If not `None`, should take a value of `"X"`, `"Y"`, or `"Z"`.

For example, `X` and `CNOT` have `basis = "X"`, whereas `ControlledPhaseShift` and `RZ` have `basis = "Z"`.

Type
str or None

batch_size

Batch size of the operator if it is used with broadcasted parameters.

The `batch_size` is determined based on `ndim_params` and the provided parameters for the operator. If (some of) the latter have an additional dimension, and this dimension has the same size for all parameters, its size is the batch size of the operator. If no parameter has an additional dimension, the batch size is `None`.

Returns
Size of the parameter broadcasting dimension if present, else `None`.

Return type
int or None

control_wires

Control wires of the operator.

For operations that are not controlled, this is an empty `Wires` object of length `0`.

Returns
The control wires of the operation.

Return type
Wires

grad_method = 'A'

grad_recipe = None

Gradient recipe for the parameter-shift method.

This is a tuple with one nested list per operation parameter. For parameter ϕ_k, the nested list contains elements of the form $[c_i, a_i, s_i]$ where i is the index of the term, resulting in a gradient recipe of

$$\frac{\partial}{\partial\phi_k}f = \sum_i c_i f(a_i\phi_k + s_i).$$

If `None`, the default gradient recipe containing the two terms $[c_0, a_0, s_0] = [1/2, 1, \pi/2]$ and $[c_1, a_1, s_1] = [-1/2, 1, -\pi/2]$ is assumed for every parameter.

Type
tuple(Union(list[list[float]], None)) or None

has_adjoint = True

has_decomposition = True

has_diagonalizing_gates = False

has_generator = True

has_matrix = True

hash

Integer hash that uniquely represents the operator.

Type
int

hyperparameters

Dictionary of non-trainable variables that this operation depends on.

Type
dict

id

Custom string to label a specific operator instance.

is_hermitian

This property determines if an operator is hermitian.

name

String for the name of the operator.

ndim_params

Number of dimensions per trainable parameter of the operator.

By default, this property returns the numbers of dimensions of the parameters used for the operator creation. If the parameter sizes for an operator subclass are fixed, this property can be overwritten to return the fixed value.

Returns
Number of dimensions for each trainable parameter.

Return type
tuple

num_params = 1

num_wires = 2

Number of wires the operator acts on.

parameter_frequencies = [(1,)]

parameters

Trainable parameters that the operator depends on.

pauli_rep

A `PauliSentence` representation of the Operator, or `None` if it doesn't have one.

wires

Wires that the operator acts on.

Returns
wires

Return type
Wires

adjoint()	Create an operation that is the adjoint of this one.
compute_decomposition(phi, wires)	Representation of the operator as a product of other operators (static method).
compute_diagonalizing_gates(*params, wires, ...)	Sequence of gates that diagonalize the operator in the computational basis (static method).
compute_eigvals(*params, **hyperparams)	Eigenvalues of the operator in the computational basis (static method).
compute_matrix(phi)	Representation of the operator as a canonical matrix in the computational basis (static method).
compute_sparse_matrix(*params, **hyperparams)	Representation of the operator as a sparse matrix in the computational basis (static method).
decomposition()	Representation of the operator as a product of other operators.
diagonalizing_gates()	Sequence of gates that diagonalize the operator in the computational basis.
eigvals()	Eigenvalues of the operator in the computational basis.
expand()	Returns a tape that contains the decomposition of the operator.
generator()	Generator of an operator that is in single-parameter-form.
label([decimals, base_label, cache])	A customizable string representation of the operator.
map_wires(wire_map)	Returns a copy of the current operator with its wires changed according to the given wire map.
matrix([wire_order])	Representation of the operator as a matrix in the computational basis.
pow(z)	A list of new operators equal to this one raised to the given power.
queue([context])	Append the operator to the Operator queue.
simplify()	Reduce the depth of nested operators to the minimum.
single_qubit_rot_angles()	The parameters required to implement a single-qubit gate as an equivalent `Rot` gate, up to a global phase.
sparse_matrix([wire_order])	Representation of the operator as a sparse matrix in the computational basis.
terms()	Representation of the operator as a linear combination of other operators.
validate_subspace(subspace)	Validate the subspace for qutrit operations.

adjoint()

Create an operation that is the adjoint of this one.

Adjointed operations are the conjugated and transposed version of the original operation. Adjointed ops are equivalent to the inverted operation for unitary gates.

Returns

The adjointed operation.

static compute_decomposition(*phi*, *wires*)

Representation of the operator as a product of other operators (static method).

$$O = O_1 O_2 \dots O_n.$$

Note: Operations making up the decomposition should be queued within the `compute_decomposition`

method.

See also:

`decomposition()`.

Parameters

- **`*params`** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **`wires`** (*Iterable[Any], Wires*) – wires that the operator acts on
- **`**hyperparams`** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
decomposition of the operator

Return type
list[Operator]

static compute_diagonalizing_gates(**params*, *wires*, ***hyperparams*)

Sequence of gates that diagonalize the operator in the computational basis (static method).

Given the eigendecomposition $O = U\Sigma U^{\dagger}$ where Σ is a diagonal matrix containing the eigenvalues, the sequence of diagonalizing gates implements the unitary $U^{\dagger}$.

The diagonalizing gates rotate the state into the eigenbasis of the operator.

See also:

`diagonalizing_gates()`.

Parameters

- **`params`** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **`wires`** (*Iterable[Any], Wires*) – wires that the operator acts on
- **`hyperparams`** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
list of diagonalizing gates

Return type
list[.Operator]

static compute_eigvals(**params*, ***hyperparams*)

Eigenvalues of the operator in the computational basis (static method).

If *diagonalizing_gates* are specified and implement a unitary $U^{\dagger}$, the operator can be reconstructed as

$$O = U\Sigma U^{\dagger},$$

where Σ is the diagonal matrix containing the eigenvalues.

Otherwise, no particular order for the eigenvalues is guaranteed.

See also:

Operator.eigvals() and `qml.eigvals()`

Parameters

- `*params` (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- `**hyperparams` (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
eigenvalues

Return type
tensor_like

static compute_matrix(*phi*)

Representation of the operator as a canonical matrix in the computational basis (static method).

The canonical matrix is the textbook matrix representation that does not consider wires. Implicitly, this assumes that the wires of the operator correspond to the global wire order.

See also:

`Operator.matrix()` and `qml.matrix()`

Parameters

- `*params` (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- `**hyperparams` (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
matrix representation

Return type
tensor_like

static compute_sparse_matrix(**params*, ***hyperparams*)

Representation of the operator as a sparse matrix in the computational basis (static method).

The canonical matrix is the textbook matrix representation that does not consider wires. Implicitly, this assumes that the wires of the operator correspond to the global wire order.

See also:

`sparse_matrix()`

Parameters

- `*params` (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- `**hyperparams` (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
sparse matrix representation

Return type
scipy.sparse._csr.csr_matrix

`decomposition()`

Representation of the operator as a product of other operators.

$$O = O_1 O_2 \dots O_n$$

A `DecompositionUndefinedError` is raised if no representation by decomposition is defined.

See also:

`compute_decomposition()`.

Returns
decomposition of the operator

Return type
list[Operator]

`diagonalizing_gates()`

Sequence of gates that diagonalize the operator in the computational basis.

Given the eigendecomposition $O = U\Sigma U^\dagger$ where Σ is a diagonal matrix containing the eigenvalues, the sequence of diagonalizing gates implements the unitary $U^\dagger$.

The diagonalizing gates rotate the state into the eigenbasis of the operator.

A `DiagGatesUndefinedError` is raised if no representation by decomposition is defined.

See also:

`compute_diagonalizing_gates()`.

Returns
a list of operators

Return type
list[.Operator] or None

`eigvals()`

Eigenvalues of the operator in the computational basis.

If *`diagonalizing_gates`* are specified and implement a unitary $U^\dagger$, the operator can be reconstructed as

$$O = U\Sigma U^\dagger,$$

where Σ is the diagonal matrix containing the eigenvalues.

Otherwise, no particular order for the eigenvalues is guaranteed.

Note: When eigenvalues are not explicitly defined, they are computed automatically from the matrix representation. Currently, this computation is *not* differentiable.

A `EigvalsUndefinedError` is raised if the eigenvalues have not been defined and cannot be inferred from the matrix representation.

See also:

`compute_eigvals()`

Returns
eigenvalues

Return type
tensor_like

expand()

Returns a tape that contains the decomposition of the operator.

Returns
quantum tape

Return type
.QuantumTape

generator()

Generator of an operator that is in single-parameter-form.

For example, for operator

$$U(\phi) = e^{i\phi(0.5Y+Z\otimes X)}$$

we get the generator

```
>>> U.generator()
  (0.5) [Y0]
+ (1.0) [Z0 X1]
```

The generator may also be provided in the form of a dense or sparse Hamiltonian (using `Hermitian` and `SparseHamiltonian` respectively).

The default value to return is `None`, indicating that the operation has no defined generator.

label(*decimals=None*, *base_label=None*, *cache=None*)

A customizable string representation of the operator.

Parameters

- **decimals=None** (*int*) – If `None`, no parameters are included. Else, specifies how to round the parameters.
- **base_label=None** (*str*) – overwrite the non-parameter component of the label
- **cache=None** (*dict*) – dictionary that carries information between label calls in the same drawing

Returns
label to use in drawings

Return type
str

Example:

```
>>> op = qml.RX(1.23456, wires=0)
>>> op.label()
"RX"
>>> op.label(base_label="my_label")
"my_label"
>>> op = qml.RX(1.23456, wires=0, id="test_data")
```

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```
>>> op.label()
"RX("test_data")"
>>> op.label(decimals=2)
"RX\n(1.23,"test_data")"
>>> op.label(base_label="my_label")
"my_label("test_data")"
>>> op.label(decimals=2, base_label="my_label")
"my_label\n(1.23,"test_data")"
```

If the operation has a matrix-valued parameter and a cache dictionary is provided, unique matrices will be cached in the `'matrices'` key list. The label will contain the index of the matrix in the `'matrices'` list.

```
>>> op2 = qml.QubitUnitary(np.eye(2), wires=0)
>>> cache = {'matrices': []}
>>> op2.label(cache=cache)
'U(M0)'
>>> cache['matrices']
[tensor([[1., 0.],
 [0., 1.]], requires_grad=True)]
>>> op3 = qml.QubitUnitary(np.eye(4), wires=(0,1))
>>> op3.label(cache=cache)
'U(M1)'
>>> cache['matrices']
[tensor([[1., 0.],
        [0., 1.]], requires_grad=True),
tensor([[1., 0., 0., 0.],
        [0., 1., 0., 0.],
        [0., 0., 1., 0.],
        [0., 0., 0., 1.]], requires_grad=True)]
```

map_wires(*wire_map: dict*)

Returns a copy of the current operator with its wires changed according to the given wire map.

Parameters
wire_map (*dict*) – dictionary containing the old wires as keys and the new wires as values

Returns
new operator

Return type
.Operator

matrix(*wire_order=None*)

Representation of the operator as a matrix in the computational basis.

If `wire_order` is provided, the numerical representation considers the position of the operator's wires in the global wire order. Otherwise, the wire order defaults to the operator's wires.

If the matrix depends on trainable parameters, the result will be cast in the same autodifferentiation framework as the parameters.

A `MatrixUndefinedError` is raised if the matrix representation has not been defined.

See also:

`compute_matrix()`

Parameters
`wire_order` (*Iterable*) – global wire order, must contain all wire labels from the operator's wires

Returns
matrix representation

Return type
tensor_like

pow(*z*) → List[Operator]

A list of new operators equal to this one raised to the given power.

Parameters
z (*float*) – exponent for the operator

Returns
list[`Operator`]

queue(*context=<class 'pennylane.queuing.QueuingManager'>*)

Append the operator to the Operator queue.

simplify() → Operator

Reduce the depth of nested operators to the minimum.

Returns
simplified operator

Return type
.Operator

single_qubit_rot_angles()

The parameters required to implement a single-qubit gate as an equivalent `Rot` gate, up to a global phase.

Returns
A list of values $[\phi, \theta, \omega]$ such that $RZ(\omega)RY(\theta)RZ(\phi)$ is equivalent to the original operation.

Return type
tuple[float, float, float]

sparse_matrix(*wire_order=None*)

Representation of the operator as a sparse matrix in the computational basis.

If `wire_order` is provided, the numerical representation considers the position of the operator's wires in the global wire order. Otherwise, the wire order defaults to the operator's wires.

A `SparseMatrixUndefinedError` is raised if the sparse matrix representation has not been defined.

See also:

`compute_sparse_matrix()`

Parameters
`wire_order` (*Iterable*) – global wire order, must contain all wire labels from the operator's wires

Returns
sparse matrix representation

Return type
scipy.sparse._csr.csr_matrix

terms()

Representation of the operator as a linear combination of other operators.

$$O = \sum_i c_i O_i$$

A TermsUndefinedError is raised if no representation by terms is defined.

Returns
list of coefficients c_i and list of operations O_i

Return type
tuple[list[tensor_like or float], list[.Operation]]

static validate_subspace(*subspace*)

Validate the subspace for qutrit operations.

This method determines whether a given subspace for qutrit operations is defined correctly or not. If not, a *ValueError* is thrown.

Parameters
subspace (*tuple[int]*) – Subspace to check for correctness

GPi

class GPi(*phi*, *wires*)

Bases: Operation

IonQ native GPi gate.

$$\mathtt{GPi}(\phi) = \begin{bmatrix} 0 & e^{-i\phi} \\ e^{i\phi} & 0 \end{bmatrix}.$$

Details:

- Number of wires: 1
- Number of parameters: 1

Parameters

- **phi** (*float*) – the phase angle
- **wires** (*int*) – the subsystem the gate acts on
- **id** (*str or None*) – String representing the operation (optional)

arithmetic_depth	Arithmetic depth of the operator.
basis	The basis of an operation, or for controlled gates, of the target operation.
batch_size	Batch size of the operator if it is used with broadcasted parameters.
control_wires	Control wires of the operator.
grad_method	
grad_recipe	Gradient recipe for the parameter-shift method.
has_adjoint	
has_decomposition	
has_diagonalizing_gates	
has_generator	
has_matrix	
hash	Integer hash that uniquely represents the operator.
hyperparameters	Dictionary of non-trainable variables that this operation depends on.
id	Custom string to label a specific operator instance.
is_hermitian	This property determines if an operator is hermitian.
name	String for the name of the operator.
ndim_params	Number of dimensions per trainable parameter of the operator.
num_params	
num_wires	Number of wires the operator acts on.
parameter_frequencies	Returns the frequencies for each operator parameter with respect to an expectation value of the form $\langle\psi\vert U(\mathbf{p})^\dagger \hat{O} U(\mathbf{p})\vert\psi\rangle$.
parameters	Trainable parameters that the operator depends on.
pauli_rep	A `PauliSentence` representation of the Operator, or `None` if it doesn't have one.
wires	Wires that the operator acts on.

arithmetic_depth

Arithmetic depth of the operator.

basis

The basis of an operation, or for controlled gates, of the target operation. If not `None`, should take a value of `"X"`, `"Y"`, or `"Z"`.

For example, `X` and `CNOT` have `basis = "X"`, whereas `ControlledPhaseShift` and `RZ` have `basis = "Z"`.

Type

str or None

batch_size

Batch size of the operator if it is used with broadcasted parameters.

The batch_size is determined based on ndim_params and the provided parameters for the operator. If (some of) the latter have an additional dimension, and this dimension has the same size for all parameters, its size is the batch size of the operator. If no parameter has an additional dimension, the batch size is None.

Returns
Size of the parameter broadcasting dimension if present, else None.

Return type
int or None

control_wires

Control wires of the operator.

For operations that are not controlled, this is an empty Wires object of length 0.

Returns
The control wires of the operation.

Return type
Wires

grad_method = 'F'

grad_recipe = None

Gradient recipe for the parameter-shift method.

This is a tuple with one nested list per operation parameter. For parameter ϕ_k, the nested list contains elements of the form $[c_i, a_i, s_i]$ where i is the index of the term, resulting in a gradient recipe of

$$\frac{\partial}{\partial\phi_k}f = \sum_i c_i f(a_i\phi_k + s_i).$$

If None, the default gradient recipe containing the two terms $[c_0, a_0, s_0] = [1/2, 1, \pi/2]$ and $[c_1, a_1, s_1] = [-1/2, 1, -\pi/2]$ is assumed for every parameter.

Type
tuple(Union(list[list[float]], None)) or None

has_adjoint = True

has_decomposition = False

has_diagonalizing_gates = False

has_generator = False

has_matrix = True

hash

Integer hash that uniquely represents the operator.

Type
int

hyperparameters

Dictionary of non-trainable variables that this operation depends on.

Type
dict

id

Custom string to label a specific operator instance.

is_hermitian

This property determines if an operator is hermitian.

name

String for the name of the operator.

ndim_params

Number of dimensions per trainable parameter of the operator.

By default, this property returns the numbers of dimensions of the parameters used for the operator creation. If the parameter sizes for an operator subclass are fixed, this property can be overwritten to return the fixed value.

Returns
Number of dimensions for each trainable parameter.

Return type
tuple

num_params = 1

num_wires = 1

Number of wires the operator acts on.

parameter_frequencies

Returns the frequencies for each operator parameter with respect to an expectation value of the form $\langle\psi|U(\mathbf{p})^\dagger\hat{O}U(\mathbf{p})|\psi\rangle$.

These frequencies encode the behaviour of the operator $U(\mathbf{p})$ on the value of the expectation value as the parameters are modified. For more details, please see the `pennylane.fourier` module.

Returns
Tuple of frequencies for each parameter. Note that only non-negative frequency values are returned.

Return type
list[tuple[int or float]]

Example

```
>>> op = qml.CRot(0.4, 0.1, 0.3, wires=[0, 1])
>>> op.parameter_frequencies
[(0.5, 1), (0.5, 1), (0.5, 1)]
```

For operators that define a generator, the parameter frequencies are directly related to the eigenvalues of the generator:

```
>>> op = qml.ControlledPhaseShift(0.1, wires=[0, 1])
>>> op.parameter_frequencies
[(1,)]
>>> gen = qml.generator(op, format="observable")
>>> gen_eigvals = qml.eigvals(gen)
>>> qml.gradients.eigvals_to_frequencies(tuple(gen_eigvals))
(1.0,)
```

For more details on this relationship, see `eigvals_to_frequencies()`.

parameters

Trainable parameters that the operator depends on.

pauli_rep

A PauliSentence representation of the Operator, or None if it doesn't have one.

wires

Wires that the operator acts on.

Returns
wires

Return type
Wires

adjoint()	Create an operation that is the adjoint of this one.
compute_decomposition(*params[, wires])	Representation of the operator as a product of other operators (static method).
compute_diagonalizing_gates(*params, wires, ...)	Sequence of gates that diagonalize the operator in the computational basis (static method).
compute_eigvals(*params, **hyperparams)	Eigenvalues of the operator in the computational basis (static method).
compute_matrix(phi)	Representation of the operator as a canonical matrix in the computational basis (static method).
compute_sparse_matrix(*params, **hyperparams)	Representation of the operator as a sparse matrix in the computational basis (static method).
decomposition()	Representation of the operator as a product of other operators.
diagonalizing_gates()	Sequence of gates that diagonalize the operator in the computational basis.
eigvals()	Eigenvalues of the operator in the computational basis.
expand()	Returns a tape that contains the decomposition of the operator.
generator()	Generator of an operator that is in single-parameter-form.
label([decimals, base_label, cache])	A customizable string representation of the operator.
map_wires(wire_map)	Returns a copy of the current operator with its wires changed according to the given wire map.
matrix([wire_order])	Representation of the operator as a matrix in the computational basis.
pow(z)	A list of new operators equal to this one raised to the given power.
queue([context])	Append the operator to the Operator queue.
simplify()	Reduce the depth of nested operators to the minimum.
single_qubit_rot_angles()	The parameters required to implement a single-qubit gate as an equivalent Rot gate, up to a global phase.
sparse_matrix([wire_order])	Representation of the operator as a sparse matrix in the computational basis.
terms()	Representation of the operator as a linear combination of other operators.
validate_subspace(subspace)	Validate the subspace for qutrit operations.

adjoint()

Create an operation that is the adjoint of this one.

Adjointed operations are the conjugated and transposed version of the original operation. Adjointed ops are equivalent to the inverted operation for unitary gates.

Returns
The adjointed operation.

`static compute_decomposition`(**params*, *wires=None*, ***hyperparameters*)

Representation of the operator as a product of other operators (static method).

$$O = O_1 O_2 \dots O_n.$$

Note: Operations making up the decomposition should be queued within the `compute_decomposition` method.

See also:

`decomposition()`.

Parameters

- **`*params`** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **`wires`** (*Iterable[Any], Wires*) – wires that the operator acts on
- **`**hyperparams`** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
decomposition of the operator

Return type
list[Operator]

`static compute_diagonalizing_gates`(**params*, *wires*, ***hyperparams*)

Sequence of gates that diagonalize the operator in the computational basis (static method).

Given the eigendecomposition $O = U\Sigma U^\dagger$ where Σ is a diagonal matrix containing the eigenvalues, the sequence of diagonalizing gates implements the unitary $U^\dagger$.

The diagonalizing gates rotate the state into the eigenbasis of the operator.

See also:

`diagonalizing_gates()`.

Parameters

- **`params`** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **`wires`** (*Iterable[Any], Wires*) – wires that the operator acts on
- **`hyperparams`** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
list of diagonalizing gates

Return type
list[.Operator]

static compute_eigvals(**params*, ***hyperparams*)

Eigenvalues of the operator in the computational basis (static method).

If `diagonalizing_gates` are specified and implement a unitary $U^\dagger$, the operator can be reconstructed as

$$O = U\Sigma U^\dagger,$$

where Σ is the diagonal matrix containing the eigenvalues.

Otherwise, no particular order for the eigenvalues is guaranteed.

See also:

`Operator.eigvals()` and `qml.eigvals()`

Parameters

- ***params** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- ****hyperparams** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
eigenvalues

Return type
tensor_like

static compute_matrix(*phi*)

Representation of the operator as a canonical matrix in the computational basis (static method).

The canonical matrix is the textbook matrix representation that does not consider wires. Implicitly, this assumes that the wires of the operator correspond to the global wire order.

See also:

`Operator.matrix()` and `qml.matrix()`

Parameters

- ***params** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- ****hyperparams** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
matrix representation

Return type
tensor_like

static compute_sparse_matrix(**params*, ***hyperparams*)

Representation of the operator as a sparse matrix in the computational basis (static method).

The canonical matrix is the textbook matrix representation that does not consider wires. Implicitly, this assumes that the wires of the operator correspond to the global wire order.

See also:

`sparse_matrix()`

Parameters

- ***params** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- ****hyperparams** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
sparse matrix representation

Return type
scipy.sparse._csr.csr_matrix

decomposition()

Representation of the operator as a product of other operators.

$$O = O_1 O_2 \dots O_n$$

A `DecompositionUndefinedError` is raised if no representation by decomposition is defined.

See also:

`compute_decomposition()`.

Returns
decomposition of the operator

Return type
list[Operator]

diagonalizing_gates()

Sequence of gates that diagonalize the operator in the computational basis.

Given the eigendecomposition $O = U\Sigma U^\dagger$ where Σ is a diagonal matrix containing the eigenvalues, the sequence of diagonalizing gates implements the unitary $U^\dagger$.

The diagonalizing gates rotate the state into the eigenbasis of the operator.

A `DiagGatesUndefinedError` is raised if no representation by decomposition is defined.

See also:

`compute_diagonalizing_gates()`.

Returns
a list of operators

Return type
list[.Operator] or None

eigvals()

Eigenvalues of the operator in the computational basis.

If *diagonalizing_gates* are specified and implement a unitary $U^\dagger$, the operator can be reconstructed as

$$O = U \Sigma U^\dagger,$$

where Σ is the diagonal matrix containing the eigenvalues.

Otherwise, no particular order for the eigenvalues is guaranteed.

Note: When eigenvalues are not explicitly defined, they are computed automatically from the matrix representation. Currently, this computation is *not* differentiable.

A `EigvalsUndefinedError` is raised if the eigenvalues have not been defined and cannot be inferred from the matrix representation.

See also:

`compute_eigvals()`

Returns
eigenvalues

Return type
tensor_like

expand()

Returns a tape that contains the decomposition of the operator.

Returns
quantum tape

Return type
.QuantumTape

generator()

Generator of an operator that is in single-parameter-form.

For example, for operator

$$U(\phi) = e^{i\phi(0.5Y + Z\otimes X)}$$

we get the generator

```
>>> U.generator()
  (0.5) [Y0]
+ (1.0) [Z0 X1]
```

The generator may also be provided in the form of a dense or sparse Hamiltonian (using `Hermitian` and `SparseHamiltonian` respectively).

The default value to return is `None`, indicating that the operation has no defined generator.

label(*decimals=None*, *base_label=None*, *cache=None*)

A customizable string representation of the operator.

Parameters

- **decimals=None** (*int*) – If None, no parameters are included. Else, specifies how to round the parameters.
- **base_label=None** (*str*) – overwrite the non-parameter component of the label
- **cache=None** (*dict*) – dictionary that carries information between label calls in the same drawing

Returns
label to use in drawings

Return type
str

Example:

```
>>> op = qml.RX(1.23456, wires=0)
>>> op.label()
"RX"
>>> op.label(base_label="my_label")
"my_label"
>>> op = qml.RX(1.23456, wires=0, id="test_data")
>>> op.label()
"RX("test_data")"
>>> op.label(decimals=2)
"RX\n(1.23,"test_data")"
>>> op.label(base_label="my_label")
"my_label("test_data")"
>>> op.label(decimals=2, base_label="my_label")
"my_label\n(1.23,"test_data")"
```

If the operation has a matrix-valued parameter and a cache dictionary is provided, unique matrices will be cached in the `'matrices'` key list. The label will contain the index of the matrix in the `'matrices'` list.

```
>>> op2 = qml.QubitUnitary(np.eye(2), wires=0)
>>> cache = {'matrices': []}
>>> op2.label(cache=cache)
'U(M0)'
>>> cache['matrices']
[tensor([[1., 0.],
 [0., 1.]], requires_grad=True)]
>>> op3 = qml.QubitUnitary(np.eye(4), wires=(0,1))
>>> op3.label(cache=cache)
'U(M1)'
>>> cache['matrices']
[tensor([[1., 0.],
        [0., 1.]], requires_grad=True),
tensor([[1., 0., 0., 0.],
        [0., 1., 0., 0.],
        [0., 0., 1., 0.],
        [0., 0., 0., 1.]], requires_grad=True)]
```

map_wires(*wire_map: dict*)

Returns a copy of the current operator with its wires changed according to the given wire map.

Parameters
wire_map (*dict*) – dictionary containing the old wires as keys and the new wires as values

Returns
new operator

Return type
.Operator

`matrix`(*wire_order=None*)

Representation of the operator as a matrix in the computational basis.

If `wire_order` is provided, the numerical representation considers the position of the operator's wires in the global wire order. Otherwise, the wire order defaults to the operator's wires.

If the matrix depends on trainable parameters, the result will be cast in the same autodifferentiation framework as the parameters.

A `MatrixUndefinedError` is raised if the matrix representation has not been defined.

See also:

`compute_matrix()`

Parameters
wire_order (*Iterable*) – global wire order, must contain all wire labels from the operator's wires

Returns
matrix representation

Return type
tensor_like

`pow`(*z*) → List[Operator]

A list of new operators equal to this one raised to the given power.

Parameters
z (*float*) – exponent for the operator

Returns
list[`Operator`]

`queue`(*context=<class 'pennylane.queuing.QueuingManager'>*)

Append the operator to the Operator queue.

`simplify`() → Operator

Reduce the depth of nested operators to the minimum.

Returns
simplified operator

Return type
.Operator

`single_qubit_rot_angles`()

The parameters required to implement a single-qubit gate as an equivalent `Rot` gate, up to a global phase.

Returns
A list of values $[\phi, \theta, \omega]$ such that $RZ(\omega)RY(\theta)RZ(\phi)$ is equivalent to the original operation.

Return type
tuple[float, float, float]

sparse_matrix(*wire_order=None*)

Representation of the operator as a sparse matrix in the computational basis.

If `wire_order` is provided, the numerical representation considers the position of the operator's wires in the global wire order. Otherwise, the wire order defaults to the operator's wires.

A `SparseMatrixUndefinedError` is raised if the sparse matrix representation has not been defined.

See also:

`compute_sparse_matrix()`

Parameters
wire_order (*Iterable*) – global wire order, must contain all wire labels from the operator's wires

Returns
sparse matrix representation

Return type
scipy.sparse._csr.csr_matrix

terms()

Representation of the operator as a linear combination of other operators.

$$O = \sum_i c_i O_i$$

A `TermsUndefinedError` is raised if no representation by terms is defined.

Returns
list of coefficients c_i and list of operations O_i

Return type
tuple[list[tensor_like or float], list[.Operation]]

static **validate_subspace**(*subspace*)

Validate the subspace for qutrit operations.

This method determines whether a given subspace for qutrit operations is defined correctly or not. If not, a *ValueError* is thrown.

Parameters
subspace (*tuple[int]*) – Subspace to check for correctness

GPi2

class **GPi2**(*phi*, *wires*)

Bases: `Operation`

IonQ native GPi2 gate.

$$\texttt{GPi2}(\phi) = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & -ie^{-i\phi} \\ -ie^{i\phi} & 1 \end{bmatrix}.$$

Details:

- Number of wires: 1
- Number of parameters: 1

Parameters

- **phi** (*float*) – the phase angle
- **wires** (*int*) – the subsystem the gate acts on
- **id** (*str or None*) – String representing the operation (optional)

arithmetic_depth	Arithmetic depth of the operator.
basis	The basis of an operation, or for controlled gates, of the target operation.
batch_size	Batch size of the operator if it is used with broadcasted parameters.
control_wires	Control wires of the operator.
grad_method	
grad_recipe	Gradient recipe for the parameter-shift method.
has_adjoint	
has_decomposition	
has_diagonalizing_gates	
has_generator	
has_matrix	
hash	Integer hash that uniquely represents the operator.
hyperparameters	Dictionary of non-trainable variables that this operation depends on.
id	Custom string to label a specific operator instance.
is_hermitian	This property determines if an operator is hermitian.
name	String for the name of the operator.
ndim_params	Number of dimensions per trainable parameter of the operator.
num_params	
num_wires	Number of wires the operator acts on.
parameter_frequencies	Returns the frequencies for each operator parameter with respect to an expectation value of the form $\langle\psi\|U(\mathbf{p})^\dagger\hat{O}U(\mathbf{p})\|\psi\rangle$.
parameters	Trainable parameters that the operator depends on.
pauli_rep	A `PauliSentence` representation of the Operator, or `None` if it doesn't have one.
wires	Wires that the operator acts on.

arithmetic_depth

Arithmetic depth of the operator.

basis

The basis of an operation, or for controlled gates, of the target operation. If not `None`, should take a value of `"X"`, `"Y"`, or `"Z"`.

For example, `X` and `CNOT` have `basis = "X"`, whereas `ControlledPhaseShift` and `RZ` have `basis = "Z"`.

Type
str or None

`batch_size`

Batch size of the operator if it is used with broadcasted parameters.

The `batch_size` is determined based on `ndim_params` and the provided parameters for the operator. If (some of) the latter have an additional dimension, and this dimension has the same size for all parameters, its size is the batch size of the operator. If no parameter has an additional dimension, the batch size is `None`.

Returns
Size of the parameter broadcasting dimension if present, else `None`.

Return type
int or None

`control_wires`

Control wires of the operator.

For operations that are not controlled, this is an empty `Wires` object of length `0`.

Returns
The control wires of the operation.

Return type
Wires

`grad_method = 'F'`

`grad_recipe = None`

Gradient recipe for the parameter-shift method.

This is a tuple with one nested list per operation parameter. For parameter ϕ_k, the nested list contains elements of the form $[c_i, a_i, s_i]$ where i is the index of the term, resulting in a gradient recipe of

$$\frac{\partial}{\partial\phi_k}f = \sum_i c_i f(a_i\phi_k + s_i).$$

If `None`, the default gradient recipe containing the two terms $[c_0, a_0, s_0] = [1/2, 1, \pi/2]$ and $[c_1, a_1, s_1] = [-1/2, 1, -\pi/2]$ is assumed for every parameter.

Type
tuple(Union(list[list[float]], None)) or None

`has_adjoint = True`

`has_decomposition = False`

`has_diagonalizing_gates = False`

`has_generator = False`

`has_matrix = True`

`hash`

Integer hash that uniquely represents the operator.

Type
int

hyperparameters
Dictionary of non-trainable variables that this operation depends on.

Type
dict

id
Custom string to label a specific operator instance.

is_hermitian
This property determines if an operator is hermitian.

name
String for the name of the operator.

ndim_params
Number of dimensions per trainable parameter of the operator.

By default, this property returns the numbers of dimensions of the parameters used for the operator creation. If the parameter sizes for an operator subclass are fixed, this property can be overwritten to return the fixed value.

Returns
Number of dimensions for each trainable parameter.

Return type
tuple

num_params = 1

num_wires = 1
Number of wires the operator acts on.

parameter_frequencies
Returns the frequencies for each operator parameter with respect to an expectation value of the form $\langle\psi|U(\mathbf{p})^\dagger \hat{O} U(\mathbf{p})|\psi\rangle$.

These frequencies encode the behaviour of the operator $U(\mathbf{p})$ on the value of the expectation value as the parameters are modified. For more details, please see the `pennylane.fourier` module.

Returns
Tuple of frequencies for each parameter. Note that only non-negative frequency values are returned.

Return type
list[tuple[int or float]]

Example

```
>>> op = qml.CRot(0.4, 0.1, 0.3, wires=[0, 1])
>>> op.parameter_frequencies
[(0.5, 1), (0.5, 1), (0.5, 1)]
```

For operators that define a generator, the parameter frequencies are directly related to the eigenvalues of the generator:

```
>>> op = qml.ControlledPhaseShift(0.1, wires=[0, 1])
>>> op.parameter_frequencies
[(1,)]
```

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```
>>> gen = qml.generator(op, format="observable")
>>> gen_eigvals = qml.eigvals(gen)
>>> qml.gradients.eigvals_to_frequencies(tuple(gen_eigvals))
(1.0,)
```

For more details on this relationship, see `eigvals_to_frequencies()`.

parameters

Trainable parameters that the operator depends on.

pauli_rep

A `PauliSentence` representation of the Operator, or `None` if it doesn't have one.

wires

Wires that the operator acts on.

Returns
wires

Return type
Wires

adjoint()	Create an operation that is the adjoint of this one.
compute_decomposition(*params[, wires])	Representation of the operator as a product of other operators (static method).
compute_diagonalizing_gates(*params, wires, ...)	Sequence of gates that diagonalize the operator in the computational basis (static method).
compute_eigvals(*params, **hyperparams)	Eigenvalues of the operator in the computational basis (static method).
compute_matrix(phi)	Representation of the operator as a canonical matrix in the computational basis (static method).
compute_sparse_matrix(*params, **hyperparams)	Representation of the operator as a sparse matrix in the computational basis (static method).
decomposition()	Representation of the operator as a product of other operators.
diagonalizing_gates()	Sequence of gates that diagonalize the operator in the computational basis.
eigvals()	Eigenvalues of the operator in the computational basis.
expand()	Returns a tape that contains the decomposition of the operator.
generator()	Generator of an operator that is in single-parameter-form.
label([decimals, base_label, cache])	A customizable string representation of the operator.
map_wires(wire_map)	Returns a copy of the current operator with its wires changed according to the given wire map.
matrix([wire_order])	Representation of the operator as a matrix in the computational basis.
pow(z)	A list of new operators equal to this one raised to the given power.
queue([context])	Append the operator to the Operator queue.
simplify()	Reduce the depth of nested operators to the minimum.
single_qubit_rot_angles()	The parameters required to implement a single-qubit gate as an equivalent `Rot` gate, up to a global phase.
sparse_matrix([wire_order])	Representation of the operator as a sparse matrix in the computational basis.
terms()	Representation of the operator as a linear combination of other operators.
validate_subspace(subspace)	Validate the subspace for qutrit operations.

adjoint()

Create an operation that is the adjoint of this one.

Adjointed operations are the conjugated and transposed version of the original operation. Adjointed ops are equivalent to the inverted operation for unitary gates.

Returns
The adjointed operation.

static compute_decomposition(**params*, *wires=None*, ***hyperparameters*)

Representation of the operator as a product of other operators (static method).

$$O = O_1 O_2 \dots O_n.$$

Note: Operations making up the decomposition should be queued within the `compute_decomposition`

method.

See also:

`decomposition()`.

Parameters

- **`*params`** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **`wires`** (*Iterable[Any], Wires*) – wires that the operator acts on
- **`**hyperparams`** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
decomposition of the operator

Return type
list[Operator]

static compute_diagonalizing_gates(**params*, *wires*, ***hyperparams*)

Sequence of gates that diagonalize the operator in the computational basis (static method).

Given the eigendecomposition $O = U\Sigma U^\dagger$ where Σ is a diagonal matrix containing the eigenvalues, the sequence of diagonalizing gates implements the unitary $U^\dagger$.

The diagonalizing gates rotate the state into the eigenbasis of the operator.

See also:

`diagonalizing_gates()`.

Parameters

- **`params`** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **`wires`** (*Iterable[Any], Wires*) – wires that the operator acts on
- **`hyperparams`** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
list of diagonalizing gates

Return type
list[.Operator]

static compute_eigvals(**params*, ***hyperparams*)

Eigenvalues of the operator in the computational basis (static method).

If `diagonalizing_gates` are specified and implement a unitary $U^\dagger$, the operator can be reconstructed as

$$O = U\Sigma U^\dagger,$$

where Σ is the diagonal matrix containing the eigenvalues.

Otherwise, no particular order for the eigenvalues is guaranteed.

See also:

Operator.eigvals() and `qml.eigvals()`

Parameters

- **`*params`** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **`**hyperparams`** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
eigenvalues

Return type
tensor_like

static compute_matrix(*phi*)

Representation of the operator as a canonical matrix in the computational basis (static method).

The canonical matrix is the textbook matrix representation that does not consider wires. Implicitly, this assumes that the wires of the operator correspond to the global wire order.

See also:

`Operator.matrix()` and `qml.matrix()`

Parameters

- **`*params`** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **`**hyperparams`** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
matrix representation

Return type
tensor_like

static compute_sparse_matrix(**params*, ***hyperparams*)

Representation of the operator as a sparse matrix in the computational basis (static method).

The canonical matrix is the textbook matrix representation that does not consider wires. Implicitly, this assumes that the wires of the operator correspond to the global wire order.

See also:

`sparse_matrix()`

Parameters

- **`*params`** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **`**hyperparams`** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
sparse matrix representation

Return type
scipy.sparse._csr.csr_matrix

decomposition()

Representation of the operator as a product of other operators.

$$O = O_1 O_2 \dots O_n$$

A `DecompositionUndefinedError` is raised if no representation by decomposition is defined.

See also:

`compute_decomposition()`.

Returns
decomposition of the operator

Return type
list[Operator]

diagonalizing_gates()

Sequence of gates that diagonalize the operator in the computational basis.

Given the eigendecomposition $O = U \Sigma U^{\dagger}$ where Σ is a diagonal matrix containing the eigenvalues, the sequence of diagonalizing gates implements the unitary $U^{\dagger}$.

The diagonalizing gates rotate the state into the eigenbasis of the operator.

A `DiagGatesUndefinedError` is raised if no representation by decomposition is defined.

See also:

`compute_diagonalizing_gates()`.

Returns
a list of operators

Return type
list[.Operator] or None

eigvals()

Eigenvalues of the operator in the computational basis.

If *`diagonalizing_gates`* are specified and implement a unitary $U^{\dagger}$, the operator can be reconstructed as

$$O = U \Sigma U^{\dagger},$$

where Σ is the diagonal matrix containing the eigenvalues.

Otherwise, no particular order for the eigenvalues is guaranteed.

Note: When eigenvalues are not explicitly defined, they are computed automatically from the matrix representation. Currently, this computation is *not* differentiable.

A `EigvalsUndefinedError` is raised if the eigenvalues have not been defined and cannot be inferred from the matrix representation.

See also:

`compute_eigvals()`

Returns
eigenvalues

Return type
tensor_like

expand()

Returns a tape that contains the decomposition of the operator.

Returns
quantum tape

Return type
.QuantumTape

generator()

Generator of an operator that is in single-parameter-form.

For example, for operator

$$U(\phi) = e^{i\phi(0.5Y + Z\otimes X)}$$

we get the generator

```
>>> U.generator()
  (0.5) [Y0]
+ (1.0) [Z0 X1]
```

The generator may also be provided in the form of a dense or sparse Hamiltonian (using `Hermitian` and `SparseHamiltonian` respectively).

The default value to return is `None`, indicating that the operation has no defined generator.

label(*decimals=None*, *base_label=None*, *cache=None*)

A customizable string representation of the operator.

Parameters

- **decimals=None** (*int*) – If `None`, no parameters are included. Else, specifies how to round the parameters.
- **base_label=None** (*str*) – overwrite the non-parameter component of the label
- **cache=None** (*dict*) – dictionary that carries information between label calls in the same drawing

Returns
label to use in drawings

Return type
str

Example:

```
>>> op = qml.RX(1.23456, wires=0)
>>> op.label()
"RX"
>>> op.label(base_label="my_label")
"my_label"
>>> op = qml.RX(1.23456, wires=0, id="test_data")
```

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```
>>> op.label()
"RX("test_data")"
>>> op.label(decimals=2)
"RX\n(1.23,"test_data")"
>>> op.label(base_label="my_label")
"my_label("test_data")"
>>> op.label(decimals=2, base_label="my_label")
"my_label\n(1.23,"test_data")"
```

If the operation has a matrix-valued parameter and a cache dictionary is provided, unique matrices will be cached in the `'matrices'` key list. The label will contain the index of the matrix in the `'matrices'` list.

```
>>> op2 = qml.QubitUnitary(np.eye(2), wires=0)
>>> cache = {'matrices': []}
>>> op2.label(cache=cache)
'U(M0)'
>>> cache['matrices']
[tensor([[1., 0.],
 [0., 1.]], requires_grad=True)]
>>> op3 = qml.QubitUnitary(np.eye(4), wires=(0,1))
>>> op3.label(cache=cache)
'U(M1)'
>>> cache['matrices']
[tensor([[1., 0.],
        [0., 1.]], requires_grad=True),
tensor([[1., 0., 0., 0.],
        [0., 1., 0., 0.],
        [0., 0., 1., 0.],
        [0., 0., 0., 1.]], requires_grad=True)]
```

map_wires(*wire_map: dict*)

Returns a copy of the current operator with its wires changed according to the given wire map.

Parameters
wire_map (*dict*) – dictionary containing the old wires as keys and the new wires as values

Returns
new operator

Return type
.Operator

matrix(*wire_order=None*)

Representation of the operator as a matrix in the computational basis.

If `wire_order` is provided, the numerical representation considers the position of the operator's wires in the global wire order. Otherwise, the wire order defaults to the operator's wires.

If the matrix depends on trainable parameters, the result will be cast in the same autodifferentiation framework as the parameters.

A `MatrixUndefinedError` is raised if the matrix representation has not been defined.

See also:

`compute_matrix()`

Parameters
`wire_order` (*Iterable*) – global wire order, must contain all wire labels from the operator's wires

Returns
matrix representation

Return type
tensor_like

pow(*z*) → List[Operator]

A list of new operators equal to this one raised to the given power.

Parameters
`z` (*float*) – exponent for the operator

Returns
list[`Operator`]

queue(*context=<class 'pennylane.queuing.QueuingManager'>*)

Append the operator to the Operator queue.

simplify() → Operator

Reduce the depth of nested operators to the minimum.

Returns
simplified operator

Return type
.Operator

single_qubit_rot_angles()

The parameters required to implement a single-qubit gate as an equivalent `Rot` gate, up to a global phase.

Returns
A list of values $[\phi, \theta, \omega]$ such that $RZ(\omega)RY(\theta)RZ(\phi)$ is equivalent to the original operation.

Return type
tuple[float, float, float]

sparse_matrix(*wire_order=None*)

Representation of the operator as a sparse matrix in the computational basis.

If `wire_order` is provided, the numerical representation considers the position of the operator's wires in the global wire order. Otherwise, the wire order defaults to the operator's wires.

A `SparseMatrixUndefinedError` is raised if the sparse matrix representation has not been defined.

See also:

`compute_sparse_matrix()`

Parameters
`wire_order` (*Iterable*) – global wire order, must contain all wire labels from the operator's wires

Returns
sparse matrix representation

Return type
scipy.sparse._csr.csr_matrix

terms()

Representation of the operator as a linear combination of other operators.

$$O = \sum_i c_i O_i$$

A `TermsUndefinedError` is raised if no representation by terms is defined.

Returns
list of coefficients c_i and list of operations O_i

Return type
tuple[list[tensor_like or float], list[.Operation]]

static **validate_subspace**(*subspace*)

Validate the subspace for qutrit operations.

This method determines whether a given subspace for qutrit operations is defined correctly or not. If not, a *ValueError* is thrown.

Parameters
subspace (*tuple[int]*) – Subspace to check for correctness

MS

class **MS**(*phi_0*, *phi_1*, *wires*)

Bases: `Operation`

IonQ native Mølmer-Sørenson gate.

$$\mathtt{MS}(\phi_0, \phi_1) = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 0 & 0 & -ie^{-i(\phi_0+\phi_1)} \\ 0 & 1 & -ie^{-i(\phi_0-\phi_1)} & 0 \\ 0 & -ie^{i(\phi_0-\phi_1)} & 1 & 0 \\ -ie^{i(\phi_0+\phi_1)} & 0 & 0 & 1 \end{bmatrix}.$$

Details:

- Number of wires: 2
- Number of parameters: 2

Parameters

- **phi_0** (*float*) – the first phase angle
- **phi_1** (*float*) – the second phase angle
- **wires** (*int*) – the subsystem the gate acts on
- **id** (*str or None*) – String representing the operation (optional)

arithmetic_depth	Arithmetic depth of the operator.
basis	The basis of an operation, or for controlled gates, of the target operation.
batch_size	Batch size of the operator if it is used with broadcasted parameters.
control_wires	Control wires of the operator.
grad_method	
grad_recipe	Gradient recipe for the parameter-shift method.
has_adjoint	
has_decomposition	
has_diagonalizing_gates	
has_generator	
has_matrix	
hash	Integer hash that uniquely represents the operator.
hyperparameters	Dictionary of non-trainable variables that this operation depends on.
id	Custom string to label a specific operator instance.
is_hermitian	This property determines if an operator is hermitian.
name	String for the name of the operator.
ndim_params	Number of dimensions per trainable parameter of the operator.
num_params	
num_wires	Number of wires the operator acts on.
parameter_frequencies	Returns the frequencies for each operator parameter with respect to an expectation value of the form $\langle\psi\|U(\mathbf{p})^\dagger\hat{O}U(\mathbf{p})\|\psi\rangle$.
parameters	Trainable parameters that the operator depends on.
pauli_rep	A `PauliSentence` representation of the Operator, or `None` if it doesn't have one.
wires	Wires that the operator acts on.

arithmetic_depth

Arithmetic depth of the operator.

basis

The basis of an operation, or for controlled gates, of the target operation. If not `None`, should take a value of `"X"`, `"Y"`, or `"Z"`.

For example, `X` and `CNOT` have `basis = "X"`, whereas `ControlledPhaseShift` and `RZ` have `basis = "Z"`.

Type

str or None

batch_size

Batch size of the operator if it is used with broadcasted parameters.

The `batch_size` is determined based on `ndim_params` and the provided parameters for the operator. If (some of) the latter have an additional dimension, and this dimension has the same size for all parameters, its size is the batch size of the operator. If no parameter has an additional dimension, the batch size is `None`.

Returns
Size of the parameter broadcasting dimension if present, else `None`.

Return type
int or None

control_wires

Control wires of the operator.

For operations that are not controlled, this is an empty `Wires` object of length `0`.

Returns
The control wires of the operation.

Return type
Wires

grad_method = 'F'

grad_recipe = None

Gradient recipe for the parameter-shift method.

This is a tuple with one nested list per operation parameter. For parameter ϕ_k, the nested list contains elements of the form $[c_i, a_i, s_i]$ where i is the index of the term, resulting in a gradient recipe of

$$\frac{\partial}{\partial\phi_k}f = \sum_i c_i f(a_i\phi_k + s_i).$$

If `None`, the default gradient recipe containing the two terms $[c_0, a_0, s_0] = [1/2, 1, \pi/2]$ and $[c_1, a_1, s_1] = [-1/2, 1, -\pi/2]$ is assumed for every parameter.

Type
tuple(Union(list[list[float]], None)) or None

has_adjoint = True

has_decomposition = False

has_diagonalizing_gates = False

has_generator = False

has_matrix = True

hash

Integer hash that uniquely represents the operator.

Type
int

hyperparameters

Dictionary of non-trainable variables that this operation depends on.

Type
dict

id

Custom string to label a specific operator instance.

is_hermitian

This property determines if an operator is hermitian.

name

String for the name of the operator.

ndim_params

Number of dimensions per trainable parameter of the operator.

By default, this property returns the numbers of dimensions of the parameters used for the operator creation. If the parameter sizes for an operator subclass are fixed, this property can be overwritten to return the fixed value.

Returns
Number of dimensions for each trainable parameter.

Return type
tuple

num_params = 2

num_wires = 2

Number of wires the operator acts on.

parameter_frequencies

Returns the frequencies for each operator parameter with respect to an expectation value of the form $\langle\psi|U(\mathbf{p})^\dagger\hat{O}U(\mathbf{p})|\psi\rangle$.

These frequencies encode the behaviour of the operator $U(\mathbf{p})$ on the value of the expectation value as the parameters are modified. For more details, please see the `pennylane.fourier` module.

Returns
Tuple of frequencies for each parameter. Note that only non-negative frequency values are returned.

Return type
list[tuple[int or float]]

Example

```
>>> op = qml.CRot(0.4, 0.1, 0.3, wires=[0, 1])
>>> op.parameter_frequencies
[(0.5, 1), (0.5, 1), (0.5, 1)]
```

For operators that define a generator, the parameter frequencies are directly related to the eigenvalues of the generator:

```
>>> op = qml.ControlledPhaseShift(0.1, wires=[0, 1])
>>> op.parameter_frequencies
[(1,)]
>>> gen = qml.generator(op, format="observable")
>>> gen_eigvals = qml.eigvals(gen)
>>> qml.gradients.eigvals_to_frequencies(tuple(gen_eigvals))
(1.0,)
```

For more details on this relationship, see `eigvals_to_frequencies()`.

parameters

Trainable parameters that the operator depends on.

pauli_rep

A PauliSentence representation of the Operator, or None if it doesn't have one.

wires

Wires that the operator acts on.

Returns
wires

Return type
Wires

adjoint()	Create an operation that is the adjoint of this one.
compute_decomposition(*params[, wires])	Representation of the operator as a product of other operators (static method).
compute_diagonalizing_gates(*params, wires, ...)	Sequence of gates that diagonalize the operator in the computational basis (static method).
compute_eigvals(*params, **hyperparams)	Eigenvalues of the operator in the computational basis (static method).
compute_matrix(phi_0, phi_1)	Representation of the operator as a canonical matrix in the computational basis (static method).
compute_sparse_matrix(*params, **hyperparams)	Representation of the operator as a sparse matrix in the computational basis (static method).
decomposition()	Representation of the operator as a product of other operators.
diagonalizing_gates()	Sequence of gates that diagonalize the operator in the computational basis.
eigvals()	Eigenvalues of the operator in the computational basis.
expand()	Returns a tape that contains the decomposition of the operator.
generator()	Generator of an operator that is in single-parameter-form.
label([decimals, base_label, cache])	A customizable string representation of the operator.
map_wires(wire_map)	Returns a copy of the current operator with its wires changed according to the given wire map.
matrix([wire_order])	Representation of the operator as a matrix in the computational basis.
pow(z)	A list of new operators equal to this one raised to the given power.
queue([context])	Append the operator to the Operator queue.
simplify()	Reduce the depth of nested operators to the minimum.
single_qubit_rot_angles()	The parameters required to implement a single-qubit gate as an equivalent Rot gate, up to a global phase.
sparse_matrix([wire_order])	Representation of the operator as a sparse matrix in the computational basis.
terms()	Representation of the operator as a linear combination of other operators.
validate_subspace(subspace)	Validate the subspace for qutrit operations.

adjoint()

Create an operation that is the adjoint of this one.

Adjointed operations are the conjugated and transposed version of the original operation. Adjointed ops are equivalent to the inverted operation for unitary gates.

Returns
The adjointed operation.

`static compute_decomposition`(**params*, *wires=None*, ***hyperparameters*)

Representation of the operator as a product of other operators (static method).

$$O = O_1 O_2 \dots O_n.$$

Note: Operations making up the decomposition should be queued within the `compute_decomposition` method.

See also:

`decomposition()`.

Parameters

- ***params** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **wires** (*Iterable[Any], Wires*) – wires that the operator acts on
- ****hyperparams** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
decomposition of the operator

Return type
list[Operator]

`static compute_diagonalizing_gates`(**params*, *wires*, ***hyperparams*)

Sequence of gates that diagonalize the operator in the computational basis (static method).

Given the eigendecomposition $O = U\Sigma U^{\dagger}$ where Σ is a diagonal matrix containing the eigenvalues, the sequence of diagonalizing gates implements the unitary $U^{\dagger}$.

The diagonalizing gates rotate the state into the eigenbasis of the operator.

See also:

`diagonalizing_gates()`.

Parameters

- **params** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **wires** (*Iterable[Any], Wires*) – wires that the operator acts on
- **hyperparams** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
list of diagonalizing gates

Return type
list[.Operator]

static compute_eigvals(**params*, ***hyperparams*)

Eigenvalues of the operator in the computational basis (static method).

If `diagonalizing_gates` are specified and implement a unitary $U^\dagger$, the operator can be reconstructed as

$$O = U\Sigma U^\dagger,$$

where Σ is the diagonal matrix containing the eigenvalues.

Otherwise, no particular order for the eigenvalues is guaranteed.

See also:

`Operator.eigvals()` and `qml.eigvals()`

Parameters

- ***params** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- ****hyperparams** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
eigenvalues

Return type
tensor_like

static compute_matrix(*phi_0*, *phi_1*)

Representation of the operator as a canonical matrix in the computational basis (static method).

The canonical matrix is the textbook matrix representation that does not consider wires. Implicitly, this assumes that the wires of the operator correspond to the global wire order.

See also:

`Operator.matrix()` and `qml.matrix()`

Parameters

- ***params** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- ****hyperparams** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
matrix representation

Return type
tensor_like

static compute_sparse_matrix(**params*, ***hyperparams*)

Representation of the operator as a sparse matrix in the computational basis (static method).

The canonical matrix is the textbook matrix representation that does not consider wires. Implicitly, this assumes that the wires of the operator correspond to the global wire order.

See also:

`sparse_matrix()`

Parameters

- ***params** (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- ****hyperparams** (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
sparse matrix representation

Return type
scipy.sparse._csr.csr_matrix

decomposition()

Representation of the operator as a product of other operators.

$$O = O_1 O_2 \dots O_n$$

A `DecompositionUndefinedError` is raised if no representation by decomposition is defined.

See also:

`compute_decomposition()`.

Returns
decomposition of the operator

Return type
list[Operator]

diagonalizing_gates()

Sequence of gates that diagonalize the operator in the computational basis.

Given the eigendecomposition $O = U \Sigma U^{\dagger}$ where Σ is a diagonal matrix containing the eigenvalues, the sequence of diagonalizing gates implements the unitary $U^{\dagger}$.

The diagonalizing gates rotate the state into the eigenbasis of the operator.

A `DiagGatesUndefinedError` is raised if no representation by decomposition is defined.

See also:

`compute_diagonalizing_gates()`.

Returns
a list of operators

Return type
list[.Operator] or None

eigvals()

Eigenvalues of the operator in the computational basis.

If *diagonalizing_gates* are specified and implement a unitary $U^{\dagger}$, the operator can be reconstructed as

$$O = U\Sigma U^{\dagger},$$

where Σ is the diagonal matrix containing the eigenvalues.

Otherwise, no particular order for the eigenvalues is guaranteed.

Note: When eigenvalues are not explicitly defined, they are computed automatically from the matrix representation. Currently, this computation is *not* differentiable.

A `EigvalsUndefinedError` is raised if the eigenvalues have not been defined and cannot be inferred from the matrix representation.

See also:

`compute_eigvals()`

Returns
eigenvalues

Return type
tensor_like

expand()

Returns a tape that contains the decomposition of the operator.

Returns
quantum tape

Return type
.QuantumTape

generator()

Generator of an operator that is in single-parameter-form.

For example, for operator

$$U(\phi) = e^{i\phi(0.5Y + Z\otimes X)}$$

we get the generator

```
>>> U.generator()
  (0.5) [Y0]
+ (1.0) [Z0 X1]
```

The generator may also be provided in the form of a dense or sparse Hamiltonian (using `Hermitian` and `SparseHamiltonian` respectively).

The default value to return is `None`, indicating that the operation has no defined generator.

label(*decimals=None*, *base_label=None*, *cache=None*)

A customizable string representation of the operator.

Parameters

- **decimals=None** (*int*) – If None, no parameters are included. Else, specifies how to round the parameters.
- **base_label=None** (*str*) – overwrite the non-parameter component of the label
- **cache=None** (*dict*) – dictionary that carries information between label calls in the same drawing

Returns
label to use in drawings

Return type
str

Example:

```
>>> op = qml.RX(1.23456, wires=0)
>>> op.label()
"RX"
>>> op.label(base_label="my_label")
"my_label"
>>> op = qml.RX(1.23456, wires=0, id="test_data")
>>> op.label()
"RX("test_data")"
>>> op.label(decimals=2)
"RX\n(1.23,"test_data")"
>>> op.label(base_label="my_label")
"my_label("test_data")"
>>> op.label(decimals=2, base_label="my_label")
"my_label\n(1.23,"test_data")"
```

If the operation has a matrix-valued parameter and a cache dictionary is provided, unique matrices will be cached in the 'matrices' key list. The label will contain the index of the matrix in the 'matrices' list.

```
>>> op2 = qml.QubitUnitary(np.eye(2), wires=0)
>>> cache = {'matrices': []}
>>> op2.label(cache=cache)
'U(M0)'
>>> cache['matrices']
[tensor([[1., 0.],
 [0., 1.]], requires_grad=True)]
>>> op3 = qml.QubitUnitary(np.eye(4), wires=(0,1))
>>> op3.label(cache=cache)
'U(M1)'
>>> cache['matrices']
[tensor([[1., 0.],
        [0., 1.]], requires_grad=True),
tensor([[1., 0., 0., 0.],
        [0., 1., 0., 0.],
        [0., 0., 1., 0.],
        [0., 0., 0., 1.]], requires_grad=True)]
```

map_wires(*wire_map: dict*)

Returns a copy of the current operator with its wires changed according to the given wire map.

Parameters
wire_map (*dict*) – dictionary containing the old wires as keys and the new wires as values

Returns
new operator

Return type
.Operator

`matrix`(*wire_order=None*)

Representation of the operator as a matrix in the computational basis.

If `wire_order` is provided, the numerical representation considers the position of the operator's wires in the global wire order. Otherwise, the wire order defaults to the operator's wires.

If the matrix depends on trainable parameters, the result will be cast in the same autodifferentiation framework as the parameters.

A `MatrixUndefinedError` is raised if the matrix representation has not been defined.

See also:

`compute_matrix()`

Parameters
wire_order (*Iterable*) – global wire order, must contain all wire labels from the operator's wires

Returns
matrix representation

Return type
tensor_like

`pow`(*z*) → List[Operator]

A list of new operators equal to this one raised to the given power.

Parameters
z (*float*) – exponent for the operator

Returns
list[`Operator`]

`queue`(*context=<class 'pennylane.queuing.QueuingManager'>*)

Append the operator to the Operator queue.

`simplify`() → Operator

Reduce the depth of nested operators to the minimum.

Returns
simplified operator

Return type
.Operator

`single_qubit_rot_angles`()

The parameters required to implement a single-qubit gate as an equivalent `Rot` gate, up to a global phase.

Returns
A list of values $[\phi, \theta, \omega]$ such that $RZ(\omega)RY(\theta)RZ(\phi)$ is equivalent to the original operation.

Return type
tuple[float, float, float]

sparse_matrix(*wire_order=None*)

Representation of the operator as a sparse matrix in the computational basis.

If `wire_order` is provided, the numerical representation considers the position of the operator's wires in the global wire order. Otherwise, the wire order defaults to the operator's wires.

A `SparseMatrixUndefinedError` is raised if the sparse matrix representation has not been defined.

See also:

`compute_sparse_matrix()`

Parameters
wire_order (*Iterable*) – global wire order, must contain all wire labels from the operator's wires

Returns
sparse matrix representation

Return type
scipy.sparse._csr.csr_matrix

terms()

Representation of the operator as a linear combination of other operators.

$$O = \sum_i c_i O_i$$

A `TermsUndefinedError` is raised if no representation by terms is defined.

Returns
list of coefficients c_i and list of operations O_i

Return type
tuple[list[tensor_like or float], list[.Operation]]

static **validate_subspace**(*subspace*)

Validate the subspace for qutrit operations.

This method determines whether a given subspace for qutrit operations is defined correctly or not. If not, a *ValueError* is thrown.

Parameters
subspace (*tuple[int]*) – Subspace to check for correctness

PSWAP

class **PSWAP**(*phi*, *wires*)

Bases: `Operation`

Phase-SWAP gate.

$$\mathtt{PSWAP}(\phi) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & e^{i\phi} & 0 \\ 0 & e^{i\phi} & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$

Details:

- Number of wires: 2

- Number of parameters: 1
- Gradient recipe:

$$\frac{d}{d\phi}\texttt{PSWAP}(\phi) = \frac{1}{2}\left[\texttt{PSWAP}(\phi + \pi/2) - \texttt{PSWAP}(\phi - \pi/2)\right]$$

Parameters

- **phi** (*float*) – the phase angle
- **wires** (*int*) – the subsystem the gate acts on
- **id** (*str or None*) – String representing the operation (optional)

arithmetic_depth	Arithmetic depth of the operator.
basis	The basis of an operation, or for controlled gates, of the target operation.
batch_size	Batch size of the operator if it is used with broadcasted parameters.
control_wires	Control wires of the operator.
grad_method	
grad_recipe	Gradient recipe for the parameter-shift method.
has_adjoint	
has_decomposition	
has_diagonalizing_gates	
has_generator	
has_matrix	
hash	Integer hash that uniquely represents the operator.
hyperparameters	Dictionary of non-trainable variables that this operation depends on.
id	Custom string to label a specific operator instance.
is_hermitian	This property determines if an operator is hermitian.
name	String for the name of the operator.
ndim_params	Number of dimensions per trainable parameter of the operator.
num_params	
num_wires	Number of wires the operator acts on.
parameter_frequencies	Returns the frequencies for each operator parameter with respect to an expectation value of the form $\langle\psi\|U(\mathbf{p})^\dagger\hat{O}U(\mathbf{p})\|\psi\rangle$.
parameters	Trainable parameters that the operator depends on.
pauli_rep	A `PauliSentence` representation of the Operator, or `None` if it doesn't have one.
wires	Wires that the operator acts on.

arithmetic_depth

Arithmetic depth of the operator.

basis

The basis of an operation, or for controlled gates, of the target operation. If not `None`, should take a value of `"X"`, `"Y"`, or `"Z"`.

For example, `X` and `CNOT` have `basis = "X"`, whereas `ControlledPhaseShift` and `RZ` have `basis = "Z"`.

Type
str or None

batch_size

Batch size of the operator if it is used with broadcasted parameters.

The `batch_size` is determined based on `ndim_params` and the provided parameters for the operator. If (some of) the latter have an additional dimension, and this dimension has the same size for all parameters, its size is the batch size of the operator. If no parameter has an additional dimension, the batch size is `None`.

Returns
Size of the parameter broadcasting dimension if present, else `None`.

Return type
int or None

control_wires

Control wires of the operator.

For operations that are not controlled, this is an empty `Wires` object of length `0`.

Returns
The control wires of the operation.

Return type
Wires

grad_method = 'A'

grad_recipe = ([[0.5, 1, 1.5707963267948966], [-0.5, 1, -1.5707963267948966]],)

Gradient recipe for the parameter-shift method.

This is a tuple with one nested list per operation parameter. For parameter ϕ_k, the nested list contains elements of the form $[c_i, a_i, s_i]$ where i is the index of the term, resulting in a gradient recipe of

$$\frac{\partial}{\partial\phi_k}f = \sum_i c_i f(a_i\phi_k + s_i).$$

If `None`, the default gradient recipe containing the two terms $[c_0, a_0, s_0] = [1/2, 1, \pi/2]$ and $[c_1, a_1, s_1] = [-1/2, 1, -\pi/2]$ is assumed for every parameter.

Type
tuple(Union(list[list[float]], None)) or None

has_adjoint = True

has_decomposition = True

has_diagonalizing_gates = False

has_generator = False

has_matrix = True

hash

Integer hash that uniquely represents the operator.

Type
int

hyperparameters

Dictionary of non-trainable variables that this operation depends on.

Type
dict

id

Custom string to label a specific operator instance.

is_hermitian

This property determines if an operator is hermitian.

name

String for the name of the operator.

ndim_params

Number of dimensions per trainable parameter of the operator.

By default, this property returns the numbers of dimensions of the parameters used for the operator creation. If the parameter sizes for an operator subclass are fixed, this property can be overwritten to return the fixed value.

Returns
Number of dimensions for each trainable parameter.

Return type
tuple

num_params = 1

num_wires = 2

Number of wires the operator acts on.

parameter_frequencies

Returns the frequencies for each operator parameter with respect to an expectation value of the form $\langle\psi|U(\mathbf{p})^\dagger\hat{O}U(\mathbf{p})|\psi\rangle$.

These frequencies encode the behaviour of the operator $U(\mathbf{p})$ on the value of the expectation value as the parameters are modified. For more details, please see the `pennylane.fourier` module.

Returns
Tuple of frequencies for each parameter. Note that only non-negative frequency values are returned.

Return type
list[tuple[int or float]]

Example

```
>>> op = qml.CRot(0.4, 0.1, 0.3, wires=[0, 1])
>>> op.parameter_frequencies
[(0.5, 1), (0.5, 1), (0.5, 1)]
```

For operators that define a generator, the parameter frequencies are directly related to the eigenvalues of the generator:

```
>>> op = qml.ControlledPhaseShift(0.1, wires=[0, 1])
>>> op.parameter_frequencies
[(1,)]
>>> gen = qml.generator(op, format="observable")
>>> gen_eigvals = qml.eigvals(gen)
>>> qml.gradients.eigvals_to_frequencies(tuple(gen_eigvals))
(1.0,)
```

For more details on this relationship, see `eigvals_to_frequencies()`.

parameters

Trainable parameters that the operator depends on.

pauli_rep

A `PauliSentence` representation of the Operator, or `None` if it doesn't have one.

wires

Wires that the operator acts on.

Returns
wires

Return type
Wires

adjoint()	Create an operation that is the adjoint of this one.
compute_decomposition(phi, wires)	Representation of the operator as a product of other operators (static method).
compute_diagonalizing_gates(*params, wires, ...)	Sequence of gates that diagonalize the operator in the computational basis (static method).
compute_eigvals(*params, **hyperparams)	Eigenvalues of the operator in the computational basis (static method).
compute_matrix(phi)	Representation of the operator as a canonical matrix in the computational basis (static method).
compute_sparse_matrix(*params, **hyperparams)	Representation of the operator as a sparse matrix in the computational basis (static method).
decomposition()	Representation of the operator as a product of other operators.
diagonalizing_gates()	Sequence of gates that diagonalize the operator in the computational basis.
eigvals()	Eigenvalues of the operator in the computational basis.
expand()	Returns a tape that contains the decomposition of the operator.
generator()	Generator of an operator that is in single-parameter-form.
label([decimals, base_label, cache])	A customizable string representation of the operator.
map_wires(wire_map)	Returns a copy of the current operator with its wires changed according to the given wire map.
matrix([wire_order])	Representation of the operator as a matrix in the computational basis.
pow(z)	A list of new operators equal to this one raised to the given power.
queue([context])	Append the operator to the Operator queue.
simplify()	Reduce the depth of nested operators to the minimum.
single_qubit_rot_angles()	The parameters required to implement a single-qubit gate as an equivalent `Rot` gate, up to a global phase.
sparse_matrix([wire_order])	Representation of the operator as a sparse matrix in the computational basis.
terms()	Representation of the operator as a linear combination of other operators.
validate_subspace(subspace)	Validate the subspace for qutrit operations.

adjoint()

Create an operation that is the adjoint of this one.

Adjointed operations are the conjugated and transposed version of the original operation. Adjointed ops are equivalent to the inverted operation for unitary gates.

Returns
The adjointed operation.

static **compute_decomposition**(*phi*, *wires*)

Representation of the operator as a product of other operators (static method).

$$O = O_1 O_2 \dots O_n.$$

Note: Operations making up the decomposition should be queued within the `compute_decomposition`

method.

See also:

`decomposition()`.

Parameters

- **`*params`** (*`list`*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **`wires`** (*`Iterable[Any], Wires`*) – wires that the operator acts on
- **`**hyperparams`** (*`dict`*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
decomposition of the operator

Return type
list[Operator]

`static compute_diagonalizing_gates`(**params*, *wires*, ***hyperparams*)

Sequence of gates that diagonalize the operator in the computational basis (static method).

Given the eigendecomposition $O = U\Sigma U^{\dagger}$ where Σ is a diagonal matrix containing the eigenvalues, the sequence of diagonalizing gates implements the unitary $U^{\dagger}$.

The diagonalizing gates rotate the state into the eigenbasis of the operator.

See also:

`diagonalizing_gates()`.

Parameters

- **`params`** (*`list`*) – trainable parameters of the operator, as stored in the `parameters` attribute
- **`wires`** (*`Iterable[Any], Wires`*) – wires that the operator acts on
- **`hyperparams`** (*`dict`*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
list of diagonalizing gates

Return type
list[.Operator]

`static compute_eigvals`(**params*, ***hyperparams*)

Eigenvalues of the operator in the computational basis (static method).

If `diagonalizing_gates` are specified and implement a unitary $U^{\dagger}$, the operator can be reconstructed as

$$O = U\Sigma U^{\dagger},$$

where Σ is the diagonal matrix containing the eigenvalues.

Otherwise, no particular order for the eigenvalues is guaranteed.

See also:

Operator.eigvals() and `qml.eigvals()`

Parameters

- `*params` (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- `**hyperparams` (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
eigenvalues

Return type
tensor_like

static compute_matrix(*phi*)

Representation of the operator as a canonical matrix in the computational basis (static method).

The canonical matrix is the textbook matrix representation that does not consider wires. Implicitly, this assumes that the wires of the operator correspond to the global wire order.

See also:

`Operator.matrix()` and `qml.matrix()`

Parameters

- `*params` (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- `**hyperparams` (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
matrix representation

Return type
tensor_like

static compute_sparse_matrix(**params*, ***hyperparams*)

Representation of the operator as a sparse matrix in the computational basis (static method).

The canonical matrix is the textbook matrix representation that does not consider wires. Implicitly, this assumes that the wires of the operator correspond to the global wire order.

See also:

`sparse_matrix()`

Parameters

- `*params` (*list*) – trainable parameters of the operator, as stored in the `parameters` attribute
- `**hyperparams` (*dict*) – non-trainable hyperparameters of the operator, as stored in the `hyperparameters` attribute

Returns
sparse matrix representation

Return type
scipy.sparse._csr.csr_matrix

`decomposition()`

Representation of the operator as a product of other operators.

$$O = O_1 O_2 \dots O_n$$

A `DecompositionUndefinedError` is raised if no representation by decomposition is defined.

See also:

`compute_decomposition()`.

Returns
decomposition of the operator

Return type
list[Operator]

`diagonalizing_gates()`

Sequence of gates that diagonalize the operator in the computational basis.

Given the eigendecomposition $O = U\Sigma U^{\dagger}$ where Σ is a diagonal matrix containing the eigenvalues, the sequence of diagonalizing gates implements the unitary $U^{\dagger}$.

The diagonalizing gates rotate the state into the eigenbasis of the operator.

A `DiagGatesUndefinedError` is raised if no representation by decomposition is defined.

See also:

`compute_diagonalizing_gates()`.

Returns
a list of operators

Return type
list[.Operator] or None

`eigvals()`

Eigenvalues of the operator in the computational basis.

If *`diagonalizing_gates`* are specified and implement a unitary $U^{\dagger}$, the operator can be reconstructed as

$$O = U\Sigma U^{\dagger},$$

where Σ is the diagonal matrix containing the eigenvalues.

Otherwise, no particular order for the eigenvalues is guaranteed.

Note: When eigenvalues are not explicitly defined, they are computed automatically from the matrix representation. Currently, this computation is *not* differentiable.

A `EigvalsUndefinedError` is raised if the eigenvalues have not been defined and cannot be inferred from the matrix representation.

See also:

`compute_eigvals()`

Returns
eigenvalues

Return type
tensor_like

expand()

Returns a tape that contains the decomposition of the operator.

Returns
quantum tape

Return type
.QuantumTape

generator()

Generator of an operator that is in single-parameter-form.

For example, for operator

$$U(\phi) = e^{i\phi(0.5Y + Z\otimes X)}$$

we get the generator

```
>>> U.generator()
  (0.5) [Y0]
+ (1.0) [Z0 X1]
```

The generator may also be provided in the form of a dense or sparse Hamiltonian (using `Hermitian` and `SparseHamiltonian` respectively).

The default value to return is `None`, indicating that the operation has no defined generator.

label(*decimals=None*, *base_label=None*, *cache=None*)

A customizable string representation of the operator.

Parameters

- **decimals=None** (*int*) – If `None`, no parameters are included. Else, specifies how to round the parameters.
- **base_label=None** (*str*) – overwrite the non-parameter component of the label
- **cache=None** (*dict*) – dictionary that carries information between label calls in the same drawing

Returns
label to use in drawings

Return type
str

Example:

```
>>> op = qml.RX(1.23456, wires=0)
>>> op.label()
"RX"
>>> op.label(base_label="my_label")
"my_label"
>>> op = qml.RX(1.23456, wires=0, id="test_data")
```

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```
>>> op.label()
"RX("test_data")"
>>> op.label(decimals=2)
"RX\n(1.23,"test_data")"
>>> op.label(base_label="my_label")
"my_label("test_data")"
>>> op.label(decimals=2, base_label="my_label")
"my_label\n(1.23,"test_data")"
```

If the operation has a matrix-valued parameter and a cache dictionary is provided, unique matrices will be cached in the `'matrices'` key list. The label will contain the index of the matrix in the `'matrices'` list.

```
>>> op2 = qml.QubitUnitary(np.eye(2), wires=0)
>>> cache = {'matrices': []}
>>> op2.label(cache=cache)
'U(M0)'
>>> cache['matrices']
[tensor([[1., 0.],
 [0., 1.]], requires_grad=True)]
>>> op3 = qml.QubitUnitary(np.eye(4), wires=(0,1))
>>> op3.label(cache=cache)
'U(M1)'
>>> cache['matrices']
[tensor([[1., 0.],
        [0., 1.]], requires_grad=True),
tensor([[1., 0., 0., 0.],
        [0., 1., 0., 0.],
        [0., 0., 1., 0.],
        [0., 0., 0., 1.]], requires_grad=True)]
```

map_wires(*wire_map: dict*)

Returns a copy of the current operator with its wires changed according to the given wire map.

Parameters
: **wire_map** (*dict*) – dictionary containing the old wires as keys and the new wires as values

Returns
: new operator

Return type
: .Operator

matrix(*wire_order=None*)

Representation of the operator as a matrix in the computational basis.

If `wire_order` is provided, the numerical representation considers the position of the operator's wires in the global wire order. Otherwise, the wire order defaults to the operator's wires.

If the matrix depends on trainable parameters, the result will be cast in the same autodifferentiation framework as the parameters.

A `MatrixUndefinedError` is raised if the matrix representation has not been defined.

See also:

`compute_matrix()`

Parameters
`wire_order` (*Iterable*) – global wire order, must contain all wire labels from the operator's wires

Returns
matrix representation

Return type
tensor_like

`pow`(*z*) → List[Operator]

A list of new operators equal to this one raised to the given power.

Parameters
`z` (*float*) – exponent for the operator

Returns
list[`Operator`]

`queue`(*context=<class 'pennylane.queuing.QueuingManager'>*)

Append the operator to the Operator queue.

`simplify`() → Operator

Reduce the depth of nested operators to the minimum.

Returns
simplified operator

Return type
.Operator

`single_qubit_rot_angles`()

The parameters required to implement a single-qubit gate as an equivalent `Rot` gate, up to a global phase.

Returns
A list of values $[\phi, \theta, \omega]$ such that $RZ(\omega)RY(\theta)RZ(\phi)$ is equivalent to the original operation.

Return type
tuple[float, float, float]

`sparse_matrix`(*wire_order=None*)

Representation of the operator as a sparse matrix in the computational basis.

If `wire_order` is provided, the numerical representation considers the position of the operator's wires in the global wire order. Otherwise, the wire order defaults to the operator's wires.

A `SparseMatrixUndefinedError` is raised if the sparse matrix representation has not been defined.

See also:

`compute_sparse_matrix()`

Parameters
`wire_order` (*Iterable*) – global wire order, must contain all wire labels from the operator's wires

Returns
sparse matrix representation

Return type
scipy.sparse._csr.csr_matrix

terms()

Representation of the operator as a linear combination of other operators.

$$O = \sum_i c_i O_i$$

A `TermsUndefinedError` is raised if no representation by terms is defined.

Returns
list of coefficients c_i and list of operations O_i

Return type
tuple[list[tensor_like or float], list[.Operation]]

static validate_subspace(*subspace*)

Validate the subspace for qutrit operations.

This method determines whether a given subspace for qutrit operations is defined correctly or not. If not, a *ValueError* is thrown.

Parameters
subspace (*tuple[int]*) – Subspace to check for correctness

2.7.2 Class Inheritance Diagram

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