PennyLane-Cirq Documentation

Release 0.28.0

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Release 0.28.0

The PennyLane-Cirq plugin integrates the Cirq quantum computing framework with PennyLane's quantum machine learning capabilities.

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

Cirq is a software library for quantum computing.

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

CHAPTER

ONE

DEVICES

Currently, PennyLane-Cirq provides four Cirq devices for PennyLane:

CHAPTER

TWO

TUTORIALS

Check out these demos to see the PennyLane-Cirq plugin in action:

You can also try it out using any of the qubit based demos from the PennyLane documentation, for example the tutorial on qubit rotation. Simply replace `'default.qubit'` with the `'cirq.simulator'` device

```
dev = qml.device('cirq.simulator', wires=XXX)
```

2.1 Installation

This plugin requires Python version 3.8 or above, as well as PennyLane and Cirq. Installation of this plugin, as well as all dependencies, can be done using `pip`:

```
$ pip install pennylane-cirq
```

Alternatively, you can install PennyLane-Cirq from the source code by navigating to the top directory and running:

```
$ python setup.py install
```

2.1.1 Dependencies

PennyLane-Cirq requires the following libraries be installed:

- Python >= 3.8

as well as the following Python packages:

- PennyLane >= 0.17
- Cirq >= 0.10.0

To use the qsim and qsimh devices, the qsim-Cirq interface `qsimcirq` is required:

- qsimcirq

It can be installed using `pip`:

```
$ pip install qsimcirq
```

If you currently do not have Python 3 installed, we recommend Anaconda for Python 3, a distributed version of Python packaged for scientific computation.

2.1.2 Tests

To test that the PennyLane-Cirq plugin is working correctly you can run

```
$ make test
```

in the source folder.

2.1.3 Documentation

To build the HTML documentation, go to the top-level directory and run:

```
$ make docs
```

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

2.2 Support

- **Source Code:** https://github.com/PennyLaneAI/pennylane-cirq
- **Issue Tracker:** https://github.com/PennyLaneAI/pennylane-cirq/issues
- **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 Simulator device

You can instantiate the device in PennyLane as follows:

```
import pennylane as qml

dev = qml.device('cirq.simulator', wires=2)
```

This device can then be used just like other devices for the definition and evaluation of QNodes within PennyLane. A simple quantum function that returns the expectation value of a measurement and depends on three classical input parameters would look like:

```
@qml.qnode(dev)
def circuit(x, y, z):
    qml.RZ(z, wires=[0])
    qml.RY(y, wires=[0])
    qml.RX(x, wires=[0])
```

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```
    qml.CNOT(wires=[0, 1])
    return qml.expval(qml.PauliZ(wires=1))
```

You can then execute the circuit like any other function to get the quantum mechanical expectation value.

```
circuit(0.2, 0.1, 0.3)
```

2.3.1 Device options

Cirq has different ways of defining qubits, e.g., `LineQubit` or `GridQubit`. The Cirq device therefore accepts an additional argument `qubits=None` that you can use to define your own qubits and give them to the device as a list.

```
import cirq

qubits = [
  cirq.GridQubit(0, 0),
  cirq.GridQubit(0, 1),
  cirq.GridQubit(1, 0),
  cirq.GridQubit(1, 1),
]

dev = qml.device("cirq.simulator", wires=4, qubits=qubits)
```

The wire of each qubit corresponds to its index in the `qubit` list. In the above example, the wire 2 corresponds to `cirq.GridQubit(1, 0)`.

If no qubits are given, the plugin will create an array of `LineQubit` instances.

2.3.2 Custom simulators

The simulator device can also be instantiated using an optional custom simulator object:

```
import pennylane as qml
import cirq

sim = cirq.Simulator()
dev = qml.device("cirq.simulator", wires=2, simulator=sim)
```

If the simulator argument is not provided, the device will by default create a `cirq.Simulator` simulator.

2.3.3 Supported operations

The `cirq.simulator` device supports all PennyLane operations and observables.

2.4 Mixed Simulator Device

You can instantiate the mixed-state simulator device in PennyLane as follows:

```
import pennylane as qml

dev = qml.device('cirq.mixedsimulator', wires=2)
```

This device can then be used just like other devices for the definition and evaluation of QNodes within PennyLane. Unlike the `cirq.simulator` backend, this device also supports several of Cirq's custom non-unitary channels, e.g., `BitFlip` or `Depolarize`.

```
from pennylane_cirq import ops

@qml.qnode(dev)
def circuit(x, p, q):
    qml.RX(x, wires=[0])
    ops.BitFlip(p, wires=[0])
    ops.Depolarize(q, wires=[1])
    qml.CNOT(wires=[0, 1])
    return qml.expval(qml.PauliZ(wires=1))

circuit(0.2, 0.1, 0.3)
```

This device stores the internal state of the quantum simulation as a density matrix. This has additional memory overhead compared to pure-state simulation, but allows for additional channels to be performed. The density matrix can be accessed after a circuit execution using `dev.state`.

2.4.1 Device options

Cirq has different ways of defining qubits, e.g., `LineQubit` or `GridQubit`. The Cirq device therefore accepts an additional argument `qubits=None` that you can use to define your own qubits and give them to the device as a list.

```
import cirq

qubits = [
  cirq.GridQubit(0, 0),
  cirq.GridQubit(0, 1),
  cirq.GridQubit(1, 0),
  cirq.GridQubit(1, 1),
]

dev = qml.device("cirq.mixedsimulator", wires=4, qubits=qubits)
```

The wire of each qubit corresponds to its index in the `qubit` list. In the above example, the wire 2 corresponds to `cirq.GridQubit(1, 0)`.

If no qubits are given, the plugin will create an array of `LineQubit` instances.

2.4.2 Supported operations

The `cirq.mixedsimulator` device supports all PennyLane operations and observables.

It also supports the following non-unitary channels from Cirq (found in `pennylane_cirq.ops`): *BitFlip*, *PhaseFlip*, *PhaseDamp*, *AmplitudeDamp*, and *Depolarize*.

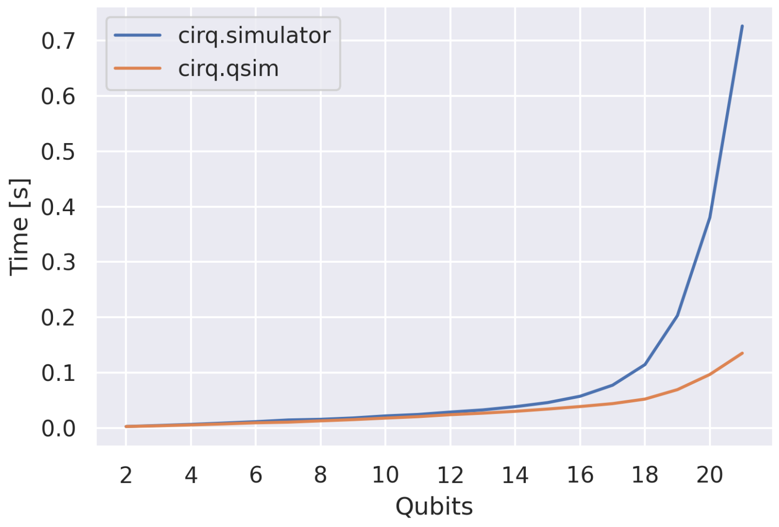
2.5 The qsim device

The qsim circuit simulator package provides two additional circuit simulators that can be used with PennyLane-Cirq:

- qsim, a Schrödinger full state-vector simulator
- qsimh, a hybrid Schrödinger-Feynman simulator. This simulator cuts the qubit lattice into two parts; each part is individually simulated using qsim, with Feynman-style path summation used to return the final result. Compared to full state-vector simulation, qsimh reduces memory requirements, at the expense of an increased runtime.

For further details see the qsim website.

For a large number of qubits, these simulators are considerably faster than the Cirq simulator:



In order to use these devices, the `qsimcirq` package must first be installed:

```
pip install qsimcirq
```

You can instantiate the qsim device in PennyLane as follows:

```
import pennylane as qml

dev = qml.device('cirq.qsim', wires=2)
```

This device can then be used just like other devices for the evaluation of QNodes within PennyLane. A simple quantum function that returns the expectation value of a measurement and depends on three classical input parameters would look like:

```
@qml.qnode(dev)
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(wires=1))
```

You can then execute the circuit like any other function to get the quantum mechanical expectation value:

```
circuit(0.2, 0.1, 0.3)
```

The qsimh device can be loaded similarly, with the addition of the keyword argument `qsimh_options` as described below.

2.5.1 Device options

qsim and qsimh use the same method of defining qubits as Cirq, e.g., `LineQubit` or `GridQubit`. As with the Cirq device, the qsim and qsimh devices therefore accept an additional argument `qubits` that can be used to define your own qubits and pass them to the device as a list.

```
import cirq

qubits = [
  cirq.GridQubit(0, 0),
  cirq.GridQubit(0, 1),
  cirq.GridQubit(1, 0),
  cirq.GridQubit(1, 1),
]

dev = qml.device("cirq.qsim", wires=4, qubits=qubits)
```

The wire of each qubit corresponds to its index in the `qubit` list. In the above example, the wire 2 corresponds to `cirq.GridQubit(1, 0)`.

If no qubits are given, the plugin will create an array of `LineQubit` instances.

qsimh options

qsimh requires specific options to be set for the simulator. These can be passed by the positional argument `qsimh_options`. See the qsimh usage documentation for further details.

```
import cirq

qubits = [
  cirq.GridQubit(0, 0),
  cirq.GridQubit(0, 1),
  cirq.GridQubit(1, 0),
  cirq.GridQubit(1, 1),
]

qsimh_options = {
```

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```
    'k': [0],
    'w': 0,
    'p': 0,
    'r': 2
}

dev = qml.device("cirq.qsimh", wires=4, qsimh_options=qsimh_options, qubits=qubits)
```

2.5.2 Supported operations

The `cirq.qsim` and `cirq.qsimh` devices support most PennyLane operations and observables, with the exceptions of inverse operations and `QubitUnitary` gates on 3 or more qubits.

For state preparation qsim relies on decomposing `BasisState` into a set of PauliX gates and QubitStateVector via Möttönen state preparation.

2.6 Pasqal Device

You can instantiate a simulator for Pasqal's neutral-atom devices in PennyLane as follows:

```
import pennylane as qml

dev = qml.device("cirq.pasqal", wires=2, control_radius=1.5)
```

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

The Pasqal device supports unique features of Pasqal's quantum computing hardware provided via Cirq, namely the `ThreeDQubit` and the notion of a `control_radius`.

```
from cirq.pasqal import ThreeDQubit
qubits = [ThreeDQubit(x, y, z)
          for x in range(2)
          for y in range(2)
          for z in range(2)]
dev = qml.device("cirq.pasqal", control_radius = 2., qubits=qubits, wires=len(qubits))

@qml.qnode(dev)
def circuit(x):
    qml.RX(x, wires=[0])
    qml.CNOT(wires=[0, 1])
    return qml.expval(qml.PauliZ(wires=1))

circuit(0.3)
```

Note that if not specified, `ThreeDGridQubits` are automatically arranged in a linear arrangement along the first coordinate axis, separated by a distance of `control_radius / 2`. That is, `(0, 0, 0)`, `(control_radius/2, 0, 0)`, `(control_radius, 0, 0)`.

For more details about Pasqal devices, consult the Cirq docs.

2.7 pennylane-cirq

This section contains the API documentation for the PennyLane-Cirq 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 Cirq devices with PennyLane.

2.7.1 Plugin overview

2.7.2 Classes

AmplitudeDamp(*params[, wires, do_queue, id])	Cirq `amplitude_damp` operation.
BitFlip(*params[, wires, do_queue, id])	Cirq `bit_flip` operation.
Depolarize(*params[, wires, do_queue, id])	Cirq `depolarize` operation.
MixedStateSimulatorDevice(wires[, shots, qubits])	Cirq mixed-state simulator device for PennyLane.
PasqalDevice(wires, control_radius[, shots, ...])	Cirq Pasqal device for PennyLane.
PhaseDamp(*params[, wires, do_queue, id])	Cirq `phase_damp` operation.
PhaseFlip(*params[, wires, do_queue, id])	Cirq `phase_flip` operation.
SimulatorDevice(wires[, shots, qubits, ...])	Cirq simulator device for PennyLane.

AmplitudeDamp

class AmplitudeDamp(**params, wires=None, do_queue=True, id=None*)

Bases: `pennylane.operation.Operation`

Cirq `amplitude_damp` operation.

See the Cirq docs for further details.

base_name	If inverse is requested, this is the name of the original operator to be inverted.
basis	The target operation for controlled gates.
control_wires	Control wires of the operator.
eigvals	Eigenvalues of an instantiated operator.
grad_method	
grad_recipe	Gradient recipe for the parameter-shift method.
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.
inverse	Boolean determining if the inverse of the operation was requested.

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Table 2 – continued from previous page

matrix	Matrix representation of an instantiated operator in the computational basis.
name	Name of the operator.
num_params	
num_wires	
par_domain	
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.
single_qubit_rot_angles	The parameters required to implement a single-qubit gate as an equivalent `Rot` gate, up to a global phase.
wires	Wires that the operator acts on.

base_name

If inverse is requested, this is the name of the original operator to be inverted.

basis = None

The target operation for controlled gates. 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

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

eigvals

Eigenvalues of an instantiated operator. Note that the eigenvalues are not guaranteed to be in any particular order.

Warning: The `eigvals` property is deprecated and will be removed in an upcoming release. Please use `qml.eigvals` instead.

Example:

```
>>> U = qml.RZ(0.5, wires=1)
>>> U.eigvals
>>> array([0.96891242-0.24740396j, 0.96891242+0.24740396j])
```

Returns eigvals representation

Return type array

grad_method = None

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_matrix = False

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.

inverse

Boolean determining if the inverse of the operation was requested.

matrix

Matrix representation of an instantiated operator in the computational basis.

Warning: The `matrix` property is deprecated and will be removed in an upcoming release. Please use `qml.matrix` instead.

Example:

```
>>> U = qml.RY(0.5, wires=1)
>>> U.matrix
>>> array([[ 0.96891242+0.j, -0.24740396+0.j],
           [ 0.24740396+0.j,  0.96891242+0.j]])
```

Returns matrix representation

Return type array

name

Name of the operator.

num_params = 1

num_wires = 1

par_domain = 'R'

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.

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]

wires

Wires that the operator acts on.

Returns wires

Return type Wires

adjoint([do_queue])	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(*params, **hyperparams)	Representation of the operator as a canonical matrix in the computational basis (static method).

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Table 3 – continued from previous page

compute_sparse_matrix(*params, **hyperparams)	Representation of the operator as a sparse matrix in the computational basis (static method).
compute_terms(*params, **hyperparams)	Representation of the operator as a linear combination of other operators (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.
expand()	Returns a tape that has recorded the decomposition of the operator.
generator()	Generator of an operator that is in single-parameter-form.
get_eigvals()	Eigenvalues of the operator in the computational basis (static method).
get_matrix([wire_order])	Representation of the operator as a matrix in the computational basis.
get_parameter_shift(idx)	Multiplier and shift for the given parameter, based on its gradient recipe.
inv()	Inverts the operator.
label([decimals, base_label, cache])	A customizable string representation of the operator.
queue([context])	Append the operator to the Operator queue.
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.

adjoint(*do_queue=False*)

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.

Parameters **do_queue** – Whether to add the adjointed gate to the context queue.

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.

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, 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:

`get_eigvals()` and `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(**params*, ***hyperparams*)

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:

`get_matrix()` and `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 matrix representation

Return type scipy.sparse.coo.coo_matrix

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

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

$$O = \sum_i c_i O_i$$

See also:

`terms()`

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 list of coefficients and list of operations

Return type tuple[list[tensor_like or float], list[Operation]]

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.

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

expand()

Returns a tape that has recorded 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.

get_eigvals()

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

If `diagonalizing_gates` are specified and implement a unitary U, 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

`get_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

`get_parameter_shift`(*idx*)

Multiplier and shift for the given parameter, based on its gradient recipe.

Parameters **`idx`** (*`int`*) – parameter index within the operation

Returns list of multiplier, coefficient, shift for each term in the gradient recipe

Return type list[[float, float, float]]

Note that the default value for `shift` is None, which is replaced by the default shift $\pi/2$.

`inv`()

Inverts the operator.

This method concatenates a string to the name of the operation, to indicate that the inverse will be used for computations.

Any subsequent call of this method will toggle between the original operation and the inverse of the operation.

Returns operation to be inverted

Return type `Operator`

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 caries 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(decimals=2)
"RX\n(1.23)"
>>> op.label(base_label="my_label")
"my_label"
>>> op.label(decimals=2, base_label="my_label")
"my_label\n(1.23)"
>>> op.inv()
>>> op.label()
"RX¹"
```

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)]
```

queue(*context=<class 'pennylane.queuing.QueuingContext'>*)
Append the operator to the Operator queue.

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.

Note: The wire_order argument is currently not implemented, and using it will raise an error.

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 matrix representation

Return type scipy.sparse.coo.coo_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.

See also:

`compute_terms()`

Returns list of coefficients c_i and list of operations O_i

Return type tuple[list[tensor_like or float], list[Operation]]

BitFlip

class BitFlip(**params*, *wires=None*, *do_queue=True*, *id=None*)

Bases: `pennylane.operation.Operation`

Cirq `bit_flip` operation.

See the Cirq docs for further details.

base_name	If inverse is requested, this is the name of the original operator to be inverted.
basis	The target operation for controlled gates.
control_wires	Control wires of the operator.
eigvals	Eigenvalues of an instantiated operator.
grad_method	
grad_recipe	Gradient recipe for the parameter-shift method.
has_matrix	

continues on next page

Table 4 – continued from previous page

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.
inverse	Boolean determining if the inverse of the operation was requested.
matrix	Matrix representation of an instantiated operator in the computational basis.
name	Name of the operator.
num_params	
num_wires	
par_domain	
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.
single_qubit_rot_angles	The parameters required to implement a single-qubit gate as an equivalent `Rot` gate, up to a global phase.
wires	Wires that the operator acts on.

base_name

If inverse is requested, this is the name of the original operator to be inverted.

basis = None

The target operation for controlled gates. 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

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

eigvals

Eigenvalues of an instantiated operator. Note that the eigenvalues are not guaranteed to be in any particular order.

Warning: The `eigvals` property is deprecated and will be removed in an upcoming release. Please use `qml.eigvals` instead.

Example:

```
>>> U = qml.RZ(0.5, wires=1)
>>> U.eigvals
>>> array([0.96891242-0.24740396j, 0.96891242+0.24740396j])
```

Returns eigvals representation

Return type array

grad_method = None

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_matrix = False

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.

inverse

Boolean determining if the inverse of the operation was requested.

matrix

Matrix representation of an instantiated operator in the computational basis.

Warning: The `matrix` property is deprecated and will be removed in an upcoming release. Please use `qml.matrix` instead.

Example:

```
>>> U = qml.RY(0.5, wires=1)
>>> U.matrix
>>> array([[ 0.96891242+0.j, -0.24740396+0.j],
           [ 0.24740396+0.j,  0.96891242+0.j]])
```

Returns matrix representation

Return type array

name
Name of the operator.

num_params = 1

num_wires = 1

par_domain = 'R'

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.

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]

wires
Wires that the operator acts on.

Returns wires

Return type Wires

adjoint([do_queue])	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).

continues on next page

Table 5 – continued from previous page

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(*params, **hyperparams)	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).
compute_terms(*params, **hyperparams)	Representation of the operator as a linear combination of other operators (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.
expand()	Returns a tape that has recorded the decomposition of the operator.
generator()	Generator of an operator that is in single-parameter-form.
get_eigvals()	Eigenvalues of the operator in the computational basis (static method).
get_matrix([wire_order])	Representation of the operator as a matrix in the computational basis.
get_parameter_shift(idx)	Multiplier and shift for the given parameter, based on its gradient recipe.
inv()	Inverts the operator.
label([decimals, base_label, cache])	A customizable string representation of the operator.
queue([context])	Append the operator to the Operator queue.
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.

adjoint(*do_queue=False*)

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.

Parameters **do_queue** – Whether to add the adjointed gate to the context queue.

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.

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, 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:

`get_eigvals()` and `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(*params, **hyperparams)`

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:

`get_matrix()` and `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 matrix representation

Return type scipy.sparse.coo.coo_matrix

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

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

$$O = \sum_i c_i O_i$$

See also:

`terms()`

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 list of coefficients and list of operations

Return type tuple[list[tensor_like or float], list[Operation]]

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.

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

expand()

Returns a tape that has recorded 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.

get_eigvals()

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

If *diagonalizing_gates* are specified and implement a unitary U, 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

get_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

get_parameter_shift(*idx*)

Multiplier and shift for the given parameter, based on its gradient recipe.

Parameters **idx** (*int*) – parameter index within the operation

Returns list of multiplier, coefficient, shift for each term in the gradient recipe

Return type list[[float, float, float]]

Note that the default value for `shift` is None, which is replaced by the default shift $\pi/2$.

inv()

Inverts the operator.

This method concatenates a string to the name of the operation, to indicate that the inverse will be used for computations.

Any subsequent call of this method will toggle between the original operation and the inverse of the operation.

Returns operation to be inverted

Return type `Operator`

`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 caries 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(decimals=2)
"RX\n(1.23)"
>>> op.label(base_label="my_label")
"my_label"
>>> op.label(decimals=2, base_label="my_label")
"my_label\n(1.23)"
>>> op.inv()
>>> op.label()
"RX¹"
```

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.],
```

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```
        [0., 1., 0., 0.],
        [0., 0., 1., 0.],
        [0., 0., 0., 1.]], requires_grad=True)]
```

queue(*context=<class 'pennylane.queuing.QueuingContext'>*)
Append the operator to the Operator queue.

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.

Note: The wire_order argument is currently not implemented, and using it will raise an error.

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 matrix representation

Return type scipy.sparse.coo.coo_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.

See also:

`compute_terms()`

Returns list of coefficients c_i and list of operations O_i

Return type tuple[list[tensor_like or float], list[Operation]]

Depolarize

class Depolarize(**params, wires=None, do_queue=True, id=None*)
Bases: `pennylane.operation.Operation`

Cirq `depolarize` operation.

See the Cirq docs for further details.

base_name	If inverse is requested, this is the name of the original operator to be inverted.
basis	The target operation for controlled gates.

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Table 6 – continued from previous page

control_wires	Control wires of the operator.
eigvals	Eigenvalues of an instantiated operator.
grad_method	
grad_recipe	Gradient recipe for the parameter-shift method.
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.
inverse	Boolean determining if the inverse of the operation was requested.
matrix	Matrix representation of an instantiated operator in the computational basis.
name	Name of the operator.
num_params	
num_wires	
par_domain	
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.
single_qubit_rot_angles	The parameters required to implement a single-qubit gate as an equivalent `Rot` gate, up to a global phase.
wires	Wires that the operator acts on.

base_name

If inverse is requested, this is the name of the original operator to be inverted.

basis = None

The target operation for controlled gates. 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

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

eigvals

Eigenvalues of an instantiated operator. Note that the eigenvalues are not guaranteed to be in any particular order.

> **Warning:** The `eigvals` property is deprecated and will be removed in an upcoming release. Please use `qml.eigvals` instead.

Example:

```
>>> U = qml.RZ(0.5, wires=1)
>>> U.eigvals
>>> array([0.96891242-0.24740396j, 0.96891242+0.24740396j])
```

Returns eigvals representation

Return type array

grad_method = None

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_matrix = False

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.

inverse

Boolean determining if the inverse of the operation was requested.

matrix

Matrix representation of an instantiated operator in the computational basis.

> **Warning:** The `matrix` property is deprecated and will be removed in an upcoming release. Please use `qml.matrix` instead.

Example:

```
>>> U = qml.RY(0.5, wires=1)
>>> U.matrix
>>> array([[ 0.96891242+0.j, -0.24740396+0.j],
           [ 0.24740396+0.j,  0.96891242+0.j]])
```

Returns matrix representation

Return type array

name
Name of the operator.

num_params = 1

num_wires = 1

par_domain = 'R'

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.

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]

wires

Wires that the operator acts on.

Returns wires

Return type Wires

adjoint([do_queue])	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(*params, **hyperparams)	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).
compute_terms(*params, **hyperparams)	Representation of the operator as a linear combination of other operators (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.
expand()	Returns a tape that has recorded the decomposition of the operator.
generator()	Generator of an operator that is in single-parameter-form.
get_eigvals()	Eigenvalues of the operator in the computational basis (static method).
get_matrix([wire_order])	Representation of the operator as a matrix in the computational basis.
get_parameter_shift(idx)	Multiplier and shift for the given parameter, based on its gradient recipe.
inv()	Inverts the operator.
label([decimals, base_label, cache])	A customizable string representation of the operator.
queue([context])	Append the operator to the Operator queue.
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.

adjoint(*do_queue=False*)

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.

Parameters **do_queue** – Whether to add the adjointed gate to the context queue.

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.

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, 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:

`get_eigvals()` and `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(*params, **hyperparams)`

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:

`get_matrix()` and `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 matrix representation

Return type scipy.sparse.coo.coo_matrix

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

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

$$O = \sum_i c_i O_i$$

See also:

`terms()`

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 list of coefficients and list of operations

Return type tuple[list[tensor_like or float], list[Operation]]

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.

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

expand()

Returns a tape that has recorded 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.

`get_eigvals()`

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

If *`diagonalizing_gates`* are specified and implement a unitary U, 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

`get_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

`get_parameter_shift`(*idx*)

Multiplier and shift for the given parameter, based on its gradient recipe.

Parameters **`idx`** (*`int`*) – parameter index within the operation

Returns list of multiplier, coefficient, shift for each term in the gradient recipe

Return type list[[float, float, float]]

Note that the default value for `shift` is None, which is replaced by the default shift $\pi/2$.

`inv`()

Inverts the operator.

This method concatenates a string to the name of the operation, to indicate that the inverse will be used for computations.

Any subsequent call of this method will toggle between the original operation and the inverse of the operation.

Returns operation to be inverted

Return type `Operator`

`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 caries 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(decimals=2)
"RX\n(1.23)"
>>> op.label(base_label="my_label")
"my_label"
>>> op.label(decimals=2, base_label="my_label")
"my_label\n(1.23)"
>>> op.inv()
>>> op.label()
"RX$^1$"
```

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)]
```

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```
>>> 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)]
```

queue(*context=<class 'pennylane.queuing.QueuingContext'>*)
Append the operator to the Operator queue.

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.

Note: The wire_order argument is currently not implemented, and using it will raise an error.

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 matrix representation

Return type scipy.sparse.coo.coo_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.

See also:

`compute_terms()`

Returns list of coefficients c_i and list of operations O_i

Return type tuple[list[tensor_like or float], list[Operation]]

MixedStateSimulatorDevice

class MixedStateSimulatorDevice(*wires*, *shots=None*, *qubits=None*)

Bases: *pennylane_cirq.simulator_device.SimulatorDevice*

Cirq mixed-state simulator 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']`).
- **shots** (*int*) – Number of circuit evaluations/random samples used to estimate expectation values of observables. Shots need to >= 1. If `None`, expectation values are calculated analytically.
- **qubits** (*List[cirq.Qubit]*) – A list of Cirq qubits that are used as wires. The wire number corresponds to the index in the list. By default, an array of `cirq.LineQubit` instances is created.

analytic	Whether shots is None or not.
author	
circuit_hash	The hash of the circuit upon the last execution.
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	Get the supported set of operations.
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 density matrix of the circuit prior to measurement.
stopping_condition	Returns the stopping condition for the device.
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 = 'Xanadu Inc'`

`circuit_hash`
The hash of the circuit upon the last execution.

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

`name = 'Cirq Mixed-State Simulator device 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`

`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 = '>=0.17.0'`

`short_name = 'cirq.mixedsimulator'`

`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", wires=2, shots=[3, 1, 2, 2, 2, 2, 6, 1, 1,
↪ 5, 12, 10, 10])
>>> dev.shots
57
```

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```
>>> dev.shot_vector
[ShotTuple(shots=3, copies=1),
 ShotTuple(shots=1, copies=1),
 ShotTuple(shots=2, copies=4),
 ShotTuple(shots=6, copies=1),
 ShotTuple(shots=1, copies=2),
 ShotTuple(shots=5, copies=1),
 ShotTuple(shots=12, copies=1),
 ShotTuple(shots=10, copies=2)]
```

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

Type list[ShotTuple[int, int]]

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

`state`
Returns the density matrix of the circuit prior to measurement.

Note: The state includes possible basis rotations for non-diagonal observables. Note that this behaviour differs from PennyLane's default.qubit plugin.

`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

`version = '0.28.0'`

`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)	Apply quantum operations, rotate the circuit into the measurement basis, and compile and execute the quantum circuit.
`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.

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Table 9 – continued from previous page

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 prior to measurement.
estimate_probability([wires, shot_range, ...])	Return the estimated probability of each computational basis state using the generated samples.
execute(circuit, **kwargs)	Execute 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.
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 a sample of an observable.
sample_basis_states(number_of_states, ...)	Sample from the computational basis states based on the state probability.
states_to_binary(samples, num_wires[, dtype])	Convert basis states from base 10 to binary representation.
statistics(observables[, shot_range, bin_size])	Process measurement results from circuit execution and return statistics.

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Table 9 – continued from previous page

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.
to_paulistring(observable)	Convert an observable to a cirq.PauliString
var(observable[, shot_range, bin_size])	Returns the variance of observable on specified wires.

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*, *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 inverse (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 Hamiltonian observables.

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

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*, ***kwargs*)

Apply quantum operations, rotate the circuit into the measurement basis, and compile and execute the quantum circuit.

This method receives a list of quantum operations queued by the QNode, and should be responsible for:

- Constructing the quantum program
- (Optional) Rotating the quantum circuit using the rotation operations provided. This diagonalizes the circuit so that arbitrary observables can be measured in the computational basis.
- Compile the circuit
- Execute the quantum circuit

Both arguments are provided as lists of PennyLane `Operation` instances. Useful properties include `name`, `wires`, and `parameters`, and `inverse`:

```
>>> op = qml.RX(0.2, wires=[0])
>>> op.name # returns the operation name
"RX"
>>> op.wires # returns a Wires object representing the wires that the operation␣
↪acts on
<Wires = [0]>
>>> op.parameters # returns a list of parameters
[0.2]
>>> op.inverse # check if the operation should be inverted
False
>>> op = qml.RX(0.2, wires=[0]).inv
>>> op.inverse
True
```

Parameters **operations** (*list[Operation]*) – operations to apply to the device

Keyword Arguments

- **rotations** (*list[Operation]*) – operations that rotate the circuit pre-measurement into the eigenbasis of the observables.
- **hash** (*int*) – the hash value of the circuit constructed by *CircuitGraph.hash*

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[tapes.QuantumTape]*) – circuits to execute on the device

Returns list of measured value(s)

Return type list[array[float]]

batch_transform(*circuit*)

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()

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_inverse_operations=False,
        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. Includes checks for inverse operations.

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

custom_expand(*fn*)

Register a custom expansion function for the device.

Example

```
dev = qml.device("default.qubit", 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:

- 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 prior to measurement.

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

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*)
Execute 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 the 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** (*CircuitGraph*) – 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 `Device.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]

`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*)

Return a sample of an observable.

The number of samples is determined by the value of `Device.shots`, which can be directly modified.

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 sampling

Returns samples in an array of dimension `(shots,)`

Return type array[float]

`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]

`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`(*observables*, *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

- **observables** (*List[Observable]*) – the observables to be measured
- **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` iff supplied operation is supported

Return type bool

to_paulistring(*observable*)

Convert an observable to a cirq.PauliString

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

PasqalDevice

class PasqalDevice(*wires*, *control_radius*, *shots=None*, *qubits=None*)

Bases: *pennylane_cirq.simulator_device.SimulatorDevice*

Cirq Pasqal device for PennyLane.

Parameters

- **wires** (*int*) – the number of wires to initialize the device with
- **control_radius** (*float*) – The maximum distance between qubits for a controlled gate. Distance is measured in units of the `ThreeDGridQubit` indices.
- **shots** (*int*) – Number of circuit evaluations/random samples used to estimate expectation values of observables. Shots need to be >= 1. If `None`, expecation values are calculated analytically.
- **qubits** (*List[cirq.ThreeDGridQubit]*) – A list of Cirq ThreeDGridQubits that are used as wires. If not specified, the ThreeDGridQubits are put in a linear arrangement along the first coordinate axis, separated by a distance of `control_radius / 2`. i.e., `(0,0,0)`, `(control_radius/2,0,0)`, `(control_radius,0,0)`, etc.

analytic	Whether shots is None or not.
author	
circuit_hash	The hash of the circuit upon the last execution.
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	Get the supported set of operations.
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.
version	
wire_map	Ordered dictionary that defines the map from user-provided wire labels to the wire labels used on this device

continues on next page

Table 10 – continued from previous page

wires	All wires that can be addressed on this device

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.

name = 'Cirq Pasqal device 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

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 = '>=0.17.0'

short_name = 'cirq.pasqal'

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", wires=2, shots=[3, 1, 2, 2, 2, 2, 6, 1, 1,
↪ 5, 12, 10, 10])
>>> dev.shots
57
>>> dev.shot_vector
[ShotTuple(shots=3, copies=1),
 ShotTuple(shots=1, copies=1),
 ShotTuple(shots=2, copies=4),
 ShotTuple(shots=6, copies=1),
 ShotTuple(shots=1, copies=2),
 ShotTuple(shots=5, copies=1),
 ShotTuple(shots=12, copies=1),
 ShotTuple(shots=10, copies=2)]
```

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

Type list[ShotTuple[int, int]]

`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: The state includes possible basis rotations for non-diagonal observables. Note that this behaviour differs from PennyLane's default.qubit plugin.

`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

`version = '0.28.0'`

`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)	Apply quantum operations, rotate the circuit into the measurement basis, and compile and execute the quantum circuit.
batch_execute(circuits)	Execute a batch of quantum circuits on the device.

continues on next page

Table 11 – continued from previous page

`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.
`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 prior to measurement.
`estimate_probability`([wires, shot_range, ...])	Return the estimated probability of each computational basis state using the generated samples.
`execute`(circuit, **kwargs)	Execute 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.
`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 a sample of an observable.

continues on next page

Table 11 – continued from previous page

sample_basis_states(number_of_states, ...)	Sample from the computational basis states based on the state probability.
states_to_binary(samples, num_wires[, dtype])	Convert basis states from base 10 to binary representation.
statistics(observables[, 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.
to_paulistring(observable)	Convert an observable to a cirq.PauliString
var(observable[, shot_range, bin_size])	Returns the variance of observable on specified wires.

`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*, *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 inverse (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 Hamiltonian observables.

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

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*, ***kwargs*)

Apply quantum operations, rotate the circuit into the measurement basis, and compile and execute the quantum circuit.

This method receives a list of quantum operations queued by the QNode, and should be responsible for:

- Constructing the quantum program
- (Optional) Rotating the quantum circuit using the rotation operations provided. This diagonalizes the circuit so that arbitrary observables can be measured in the computational basis.
- Compile the circuit
- Execute the quantum circuit

Both arguments are provided as lists of PennyLane `Operation` instances. Useful properties include `name`, `wires`, and `parameters`, and `inverse`:

```
>>> op = qml.RX(0.2, wires=[0])
>>> op.name # returns the operation name
"RX"
>>> op.wires # returns a Wires object representing the wires that the operation␣
↪acts on
<Wires = [0]>
>>> op.parameters # returns a list of parameters
[0.2]
>>> op.inverse # check if the operation should be inverted
False
>>> op = qml.RX(0.2, wires=[0]).inv
>>> op.inverse
True
```

Parameters **operations** (*list[Operation]*) – operations to apply to the device

Keyword Arguments

- **rotations** (*list[Operation]*) – operations that rotate the circuit pre-measurement into the eigenbasis of the observables.
- **hash** (*int*) – the hash value of the circuit constructed by *CircuitGraph.hash*

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[tapes.QuantumTape]*) – circuits to execute on the device

Returns list of measured value(s)

Return type list[array[float]]

batch_transform(*circuit*)

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()

Get the capabilities of this device class.

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

```python
@classmethod
def capabilities(cls):
    capabilities = super().capabilities().copy()
    capabilities.update(
        supports_inverse_operations=False,
        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. Includes checks for inverse operations.

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

custom_expand(*fn*)

Register a custom expansion function for the device.

Example

```
dev = qml.device("default.qubit", 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:

- 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 prior to measurement.

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

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*)

Execute 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 the 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** (*CircuitGraph*) – 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 `Device.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]

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*)

Return a sample of an observable.

The number of samples is determined by the value of `Device.shots`, which can be directly modified.

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 sampling

Returns samples in an array of dimension `(shots,)`

Return type array[float]

`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]

`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`(*observables*, *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

- **observables** (*List[Observable]*) – the observables to be measured
- **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` iff supplied operation is supported

Return type bool

`to_paulistring`(*observable*)

Convert an observable to a cirq.PauliString

`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

PhaseDamp

class `PhaseDamp`(**params*, *wires=None*, *do_queue=True*, *id=None*)

Bases: `pennylane.operation.Operation`

Cirq `phase_damp` operation.

See the Cirq docs for further details.

base_name	If inverse is requested, this is the name of the original operator to be inverted.
basis	The target operation for controlled gates.
control_wires	Control wires of the operator.
eigvals	Eigenvalues of an instantiated operator.
grad_method	
grad_recipe	Gradient recipe for the parameter-shift method.
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.
inverse	Boolean determining if the inverse of the operation was requested.
matrix	Matrix representation of an instantiated operator in the computational basis.
name	Name of the operator.
num_params	
num_wires	
par_domain	
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.
single_qubit_rot_angles	The parameters required to implement a single-qubit gate as an equivalent `Rot` gate, up to a global phase.
wires	Wires that the operator acts on.

base_name

If inverse is requested, this is the name of the original operator to be inverted.

basis = None

The target operation for controlled gates. 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

`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

`eigvals`
Eigenvalues of an instantiated operator. Note that the eigenvalues are not guaranteed to be in any particular order.

Warning: The `eigvals` property is deprecated and will be removed in an upcoming release. Please use `qml.eigvals` instead.

Example:

```
>>> U = qml.RZ(0.5, wires=1)
>>> U.eigvals
>>> array([0.96891242-0.24740396j, 0.96891242+0.24740396j])
```

Returns eigvals representation

Return type array

`grad_method = None`

`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_matrix = False`

`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.

`inverse`
Boolean determining if the inverse of the operation was requested.

matrix

Matrix representation of an instantiated operator in the computational basis.

> **Warning:** The `matrix` property is deprecated and will be removed in an upcoming release. Please use `qml.matrix` instead.

Example:

```
>>> U = qml.RY(0.5, wires=1)
>>> U.matrix
>>> array([[ 0.96891242+0.j, -0.24740396+0.j],
           [ 0.24740396+0.j,  0.96891242+0.j]])
```

Returns matrix representation

Return type array

name

Name of the operator.

num_params = 1

num_wires = 1

par_domain = 'R'

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.

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]

wires
Wires that the operator acts on.

Returns wires

Return type Wires

adjoint([do_queue])	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(*params, **hyperparams)	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).
compute_terms(*params, **hyperparams)	Representation of the operator as a linear combination of other operators (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.
expand()	Returns a tape that has recorded the decomposition of the operator.
generator()	Generator of an operator that is in single-parameter-form.
get_eigvals()	Eigenvalues of the operator in the computational basis (static method).
get_matrix([wire_order])	Representation of the operator as a matrix in the computational basis.
get_parameter_shift(idx)	Multiplier and shift for the given parameter, based on its gradient recipe.
inv()	Inverts the operator.
label([decimals, base_label, cache])	A customizable string representation of the operator.
queue([context])	Append the operator to the Operator queue.
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.

adjoint(*do_queue=False*)
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.

Parameters `do_queue` – Whether to add the adjointed gate to the context queue.

Returns The adjointed operation.

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

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

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

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.

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, 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:

`get_eigvals()` and `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(*params, **hyperparams)`

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:

`get_matrix()` and `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 matrix representation

Return type scipy.sparse.coo.coo_matrix

static compute_terms(**params, **hyperparams*)

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

$$O = \sum_i c_i O_i$$

See also:

`terms()`

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 list of coefficients and list of operations

Return type tuple[list[tensor_like or float], list[Operation]]

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.

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

expand()

Returns a tape that has recorded 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.

get_eigvals()

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

If *`diagonalizing_gates`* are specified and implement a unitary U, 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

get_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

`get_parameter_shift`(*idx*)

Multiplier and shift for the given parameter, based on its gradient recipe.

Parameters **`idx`** (*`int`*) – parameter index within the operation

Returns list of multiplier, coefficient, shift for each term in the gradient recipe

Return type list[[float, float, float]]

Note that the default value for `shift` is None, which is replaced by the default shift $\pi/2$.

`inv`()

Inverts the operator.

This method concatenates a string to the name of the operation, to indicate that the inverse will be used for computations.

Any subsequent call of this method will toggle between the original operation and the inverse of the operation.

Returns operation to be inverted

Return type `Operator`

`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 caries 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(decimals=2)
"RX\n(1.23)"
>>> op.label(base_label="my_label")
"my_label"
>>> op.label(decimals=2, base_label="my_label")
"my_label\n(1.23)"
```

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```
>>> op.inv()
>>> op.label()
"RX¹"
```

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)]
```

queue(*context=<class 'pennylane.queuing.QueuingContext'>*)
Append the operator to the Operator queue.

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.

Note: The wire_order argument is currently not implemented, and using it will raise an error.

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 matrix representation

Return type scipy.sparse.coo.coo_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.

See also:

`compute_terms()`

Returns list of coefficients c_i and list of operations O_i

Return type tuple[list[tensor_like or float], list[Operation]]

PhaseFlip

class PhaseFlip(**params*, *wires=None*, *do_queue=True*, *id=None*)

Bases: `pennylane.operation.Operation`

Cirq `phase_flip` operation.

See the Cirq docs for further details.

base_name	If inverse is requested, this is the name of the original operator to be inverted.
basis	The target operation for controlled gates.
control_wires	Control wires of the operator.
eigvals	Eigenvalues of an instantiated operator.
grad_method	
grad_recipe	Gradient recipe for the parameter-shift method.
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.
inverse	Boolean determining if the inverse of the operation was requested.
matrix	Matrix representation of an instantiated operator in the computational basis.
name	Name of the operator.
num_params	
num_wires	
par_domain	
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.
single_qubit_rot_angles	The parameters required to implement a single-qubit gate as an equivalent `Rot` gate, up to a global phase.
wires	Wires that the operator acts on.

base_name

If inverse is requested, this is the name of the original operator to be inverted.

basis = None

The target operation for controlled gates. 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

`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

`eigvals`
Eigenvalues of an instantiated operator. Note that the eigenvalues are not guaranteed to be in any particular order.

Warning: The `eigvals` property is deprecated and will be removed in an upcoming release. Please use `qml.eigvals` instead.

Example:

```
>>> U = qml.RZ(0.5, wires=1)
>>> U.eigvals
>>> array([0.96891242-0.24740396j, 0.96891242+0.24740396j])
```

Returns eigvals representation

Return type array

`grad_method = None`

`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_matrix = False`

`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.

inverse
Boolean determining if the inverse of the operation was requested.

matrix
Matrix representation of an instantiated operator in the computational basis.

Warning: The `matrix` property is deprecated and will be removed in an upcoming release. Please use `qml.matrix` instead.

Example:

```
>>> U = qml.RY(0.5, wires=1)
>>> U.matrix
>>> array([[ 0.96891242+0.j, -0.24740396+0.j],
           [ 0.24740396+0.j,  0.96891242+0.j]])
```

Returns matrix representation

Return type array

name
Name of the operator.

num_params = 1

num_wires = 1

par_domain = 'R'

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")
```

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```
>>> 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.

`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]

`wires`
Wires that the operator acts on.

Returns wires

Return type Wires

adjoint([do_queue])	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(*params, **hyperparams)	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).
compute_terms(*params, **hyperparams)	Representation of the operator as a linear combination of other operators (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.
expand()	Returns a tape that has recorded the decomposition of the operator.
generator()	Generator of an operator that is in single-parameter-form.
get_eigvals()	Eigenvalues of the operator in the computational basis (static method).
get_matrix([wire_order])	Representation of the operator as a matrix in the computational basis.
get_parameter_shift(idx)	Multiplier and shift for the given parameter, based on its gradient recipe.
inv()	Inverts the operator.
label([decimals, base_label, cache])	A customizable string representation of the operator.
queue([context])	Append the operator to the Operator queue.

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Table 15 – continued from previous page

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.

adjoint(*do_queue=False*)

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.

Parameters **do_queue** – Whether to add the adjointed gate to the context queue.

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.

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, 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:

`get_eigvals()` and `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`(**params*, ***hyperparams*)

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:

`get_matrix()` and `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 matrix representation

Return type scipy.sparse.coo.coo_matrix

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

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

$$O = \sum_i c_i O_i$$

See also:

`terms()`

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 list of coefficients and list of operations

Return type tuple[list[tensor_like or float], list[Operation]]

`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.

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

expand()

Returns a tape that has recorded 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.

get_eigvals()

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

If *diagonalizing_gates* are specified and implement a unitary U, 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

get_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

`get_parameter_shift`(*idx*)

Multiplier and shift for the given parameter, based on its gradient recipe.

Parameters **`idx`** (*`int`*) – parameter index within the operation

Returns list of multiplier, coefficient, shift for each term in the gradient recipe

Return type list[[float, float, float]]

Note that the default value for `shift` is None, which is replaced by the default shift $\pi/2$.

`inv`()

Inverts the operator.

This method concatenates a string to the name of the operation, to indicate that the inverse will be used for computations.

Any subsequent call of this method will toggle between the original operation and the inverse of the operation.

Returns operation to be inverted

Return type `Operator`

`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 caries 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(decimals=2)
"RX\n(1.23)"
```

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```
>>> op.label(base_label="my_label")
"my_label"
>>> op.label(decimals=2, base_label="my_label")
"my_label\n(1.23)"
>>> op.inv()
>>> op.label()
"RX¹"
```

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)]
```

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

Append the operator to the Operator queue.

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.

Note: The wire_order argument is currently not implemented, and using it will raise an error.

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 matrix representation

Return type scipy.sparse.coo.coo_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.

See also:

`compute_terms()`

Returns list of coefficients c_i and list of operations O_i

Return type tuple[list[tensor_like or float], list[Operation]]

SimulatorDevice

class `SimulatorDevice`(*wires*, *shots=None*, *qubits=None*, *simulator=None*)

Bases: `pennylane_cirq.cirq_device.CirqDevice`

Cirq simulator 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']`).
- **shots** (*int*) – Number of circuit evaluations/random samples used to estimate expectation values of observables. Shots need to >= 1. If `None`, expectation values are calculated analytically.
- **qubits** (*List[cirq.Qubit]*) – A list of Cirq qubits that are used as wires. The wire number corresponds to the index in the list. By default, an array of `cirq.LineQubit` instances is created.
- **simulator** (*Optional[cirq.Simulator]*) – Optional custom simulator object to use. If None, the default `cirq.Simulator()` will be used instead.

analytic	Whether shots is None or not.
author	
circuit_hash	The hash of the circuit upon the last execution.
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	Get the supported set of operations.
parameters	Mapping from free parameter index to the list of `Operations` in the device queue that depend on it.
pennylane_requires	

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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.
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 = 'Xanadu Inc'

circuit_hash
The hash of the circuit upon the last execution.

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

name = 'Cirq Simulator device 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

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 = '>=0.17.0'`

`short_name = 'cirq.simulator'`

`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", wires=2, shots=[3, 1, 2, 2, 2, 2, 6, 1, 1,
↪ 5, 12, 10, 10])
>>> dev.shots
57
>>> dev.shot_vector
[ShotTuple(shots=3, copies=1),
 ShotTuple(shots=1, copies=1),
 ShotTuple(shots=2, copies=4),
 ShotTuple(shots=6, copies=1),
 ShotTuple(shots=1, copies=2),
 ShotTuple(shots=5, copies=1),
 ShotTuple(shots=12, copies=1),
 ShotTuple(shots=10, copies=2)]
```

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

Type list[ShotTuple[int, int]]

`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: The state includes possible basis rotations for non-diagonal observables. Note that this behaviour differs from PennyLane's default.qubit plugin.

`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

`version = '0.28.0'`

`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)	Apply quantum operations, rotate the circuit into the measurement basis, and compile and execute the quantum circuit.
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.
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 prior to measurement.
estimate_probability([wires, shot_range, ...])	Return the estimated probability of each computational basis state using the generated samples.
execute(circuit, **kwargs)	Execute 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.
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.

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`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 a sample of an observable.
`sample_basis_states`(number_of_states, ...)	Sample from the computational basis states based on the state probability.
`states_to_binary`(samples, num_wires[, dtype])	Convert basis states from base 10 to binary representation.
`statistics`(observables[, 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.
`to_paulistring`(observable)	Convert an observable to a cirq.PauliString
`var`(observable[, shot_range, bin_size])	Returns the variance of observable on specified wires.

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*, *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 inverse (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 Hamiltonian observables.

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

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*, ***kwargs*)

Apply quantum operations, rotate the circuit into the measurement basis, and compile and execute the quantum circuit.

This method receives a list of quantum operations queued by the QNode, and should be responsible for:

- Constructing the quantum program
- (Optional) Rotating the quantum circuit using the rotation operations provided. This diagonalizes the circuit so that arbitrary observables can be measured in the computational basis.
- Compile the circuit
- Execute the quantum circuit

Both arguments are provided as lists of PennyLane `Operation` instances. Useful properties include `name`, `wires`, and `parameters`, and `inverse`:

```
>>> op = qml.RX(0.2, wires=[0])
>>> op.name # returns the operation name
"RX"
>>> op.wires # returns a Wires object representing the wires that the operation␣
↪acts on
```

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```
<Wires = [0]>
>>> op.parameters # returns a list of parameters
[0.2]
>>> op.inverse # check if the operation should be inverted
False
>>> op = qml.RX(0.2, wires=[0]).inv
>>> op.inverse
True
```

Parameters **operations** (*list[Operation]*) – operations to apply to the device

Keyword Arguments

- **rotations** (*list[Operation]*) – operations that rotate the circuit pre-measurement into the eigenbasis of the observables.
- **hash** (*int*) – the hash value of the circuit constructed by *CircuitGraph.hash*

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[tapes.QuantumTape]*) – circuits to execute on the device

Returns list of measured value(s)

Return type list[array[float]]

batch_transform(*circuit*)

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()

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_inverse_operations=False,
        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. Includes checks for inverse operations.

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

`custom_expand`(*fn*)

Register a custom expansion function for the device.

Example

```
dev = qml.device("default.qubit", 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:

- 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 prior to measurement.

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

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*)

Execute 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 the 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** (*CircuitGraph*) – 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 `Device.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]

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*)
Return a sample of an observable.

The number of samples is determined by the value of `Device.shots`, which can be directly modified.

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 sampling

Returns samples in an array of dimension `(shots,)`

Return type array[float]

`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]

`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`(*observables*, *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

- **observables** (*List[Observable]*) – the observables to be measured
- **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` iff supplied operation is supported

Return type bool

to_paulistring(*observable*)
Convert an observable to a cirq.PauliString

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

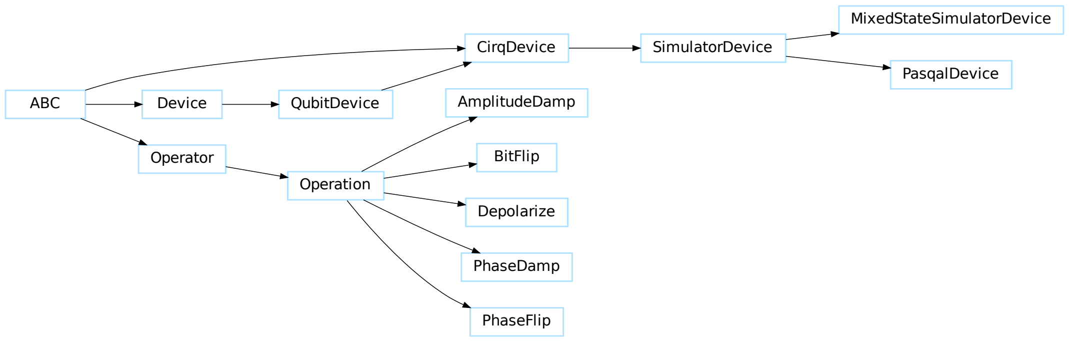
- **observable** (*str or list[str]*) – name of the observable(s)
- **wires** (*Wires*) – wires the observable(s) is to be measured on
- **par** (*tuple or list[tuple]*) – parameters for the observable(s)

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

2.7.3 Class Inheritance Diagram



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