MATH1131 Mathematics 1A – Algebra

Lecture 11: Polar Form for Complex Numbers

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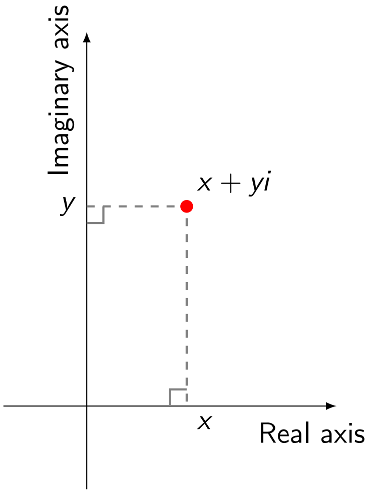
Based on slides by Jonathan Kress

Polar form of a complex number

The Cartesian form of a complex number with real part x and imaginary part y is

$$z = x + yi.$$



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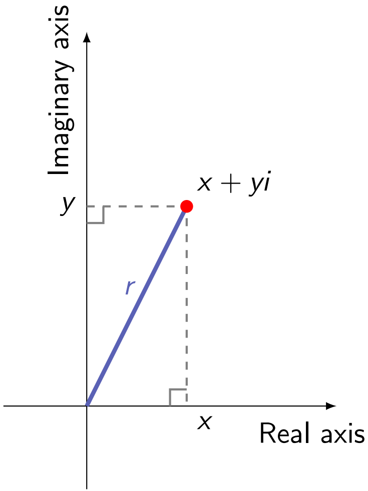

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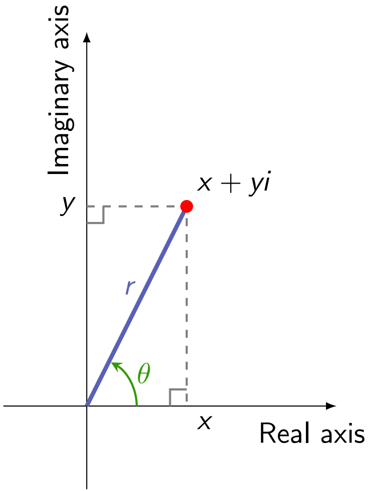
We can also describe z by its distance r from the origin and its angle θ from the positive real axis as shown.



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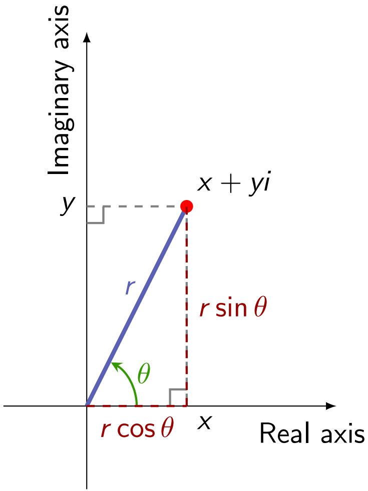
$$x = r\cos\theta, \quad y = r\sin\theta$$



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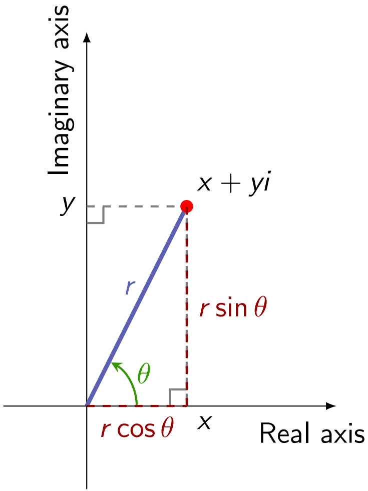
Simple trigonometry shows that

$$x = r\cos\theta, \quad y = r\sin\theta$$

and

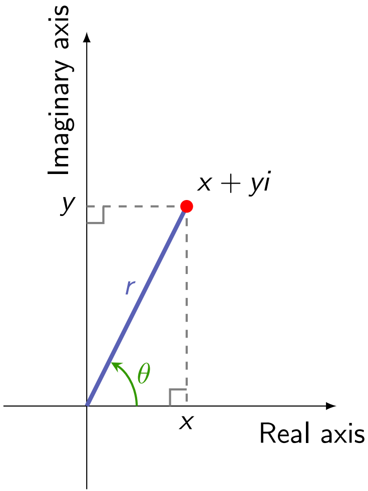
$$r = \sqrt{x^2 + y^2}, \quad \tan\theta = \frac{y}{x}.$$



Modulus and argument

We call r the modulus of $z = x + iy$ and denote it $|z|$:

$$|z| = \sqrt{x^2 + y^2}$$



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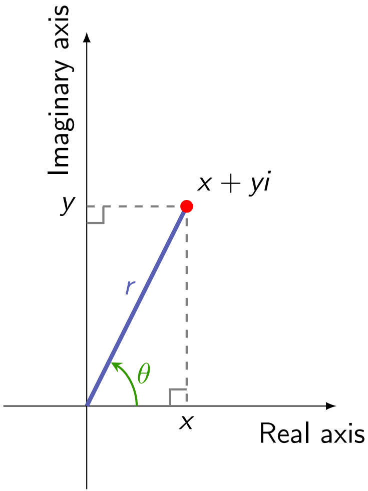
$$\tan(\arg(z)) = \frac{y}{x}$$



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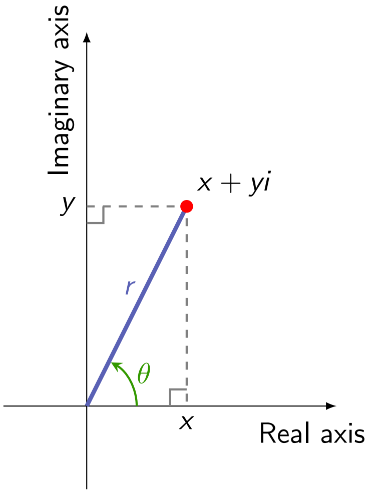
Note for any z there are many possible arguments that differ by multiples of 2π.



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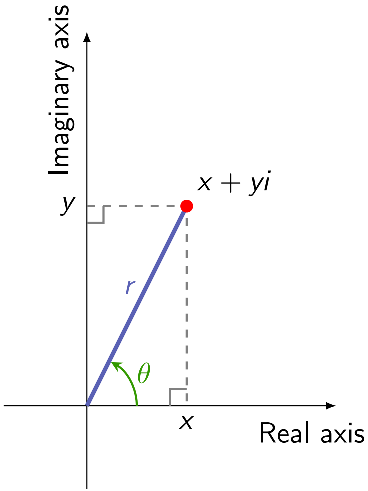
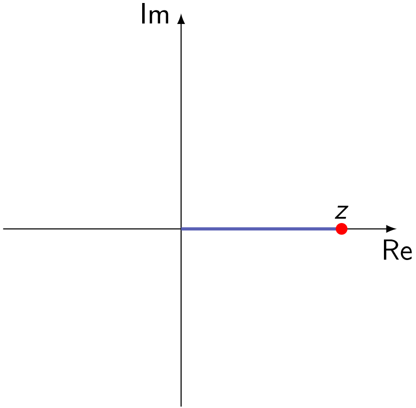
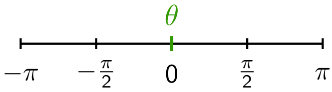
The principal argument of z is denoted $\operatorname{Arg}(z)$ and satisfies:

$$-\pi < \operatorname{Arg}(z) \leq \pi.$$



Principal argument





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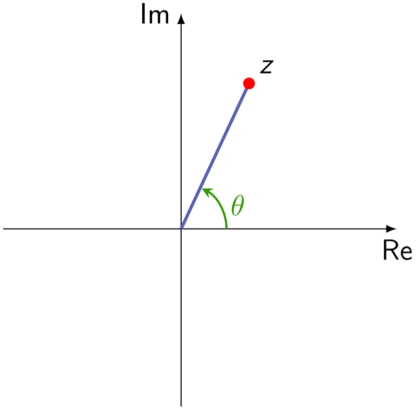

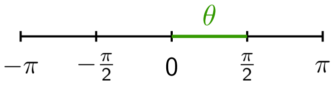

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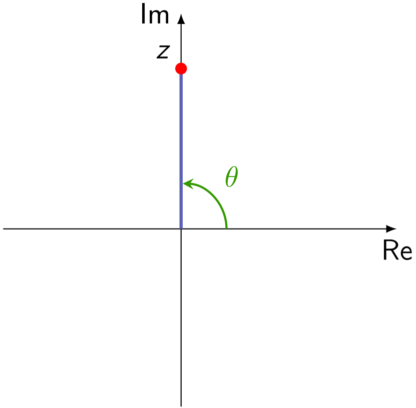

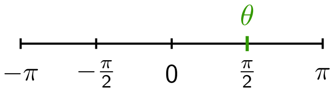

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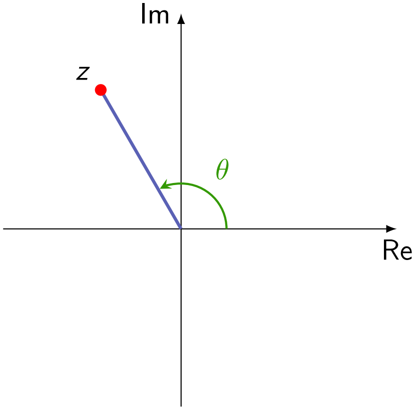

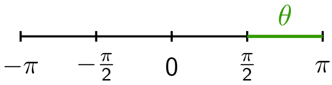

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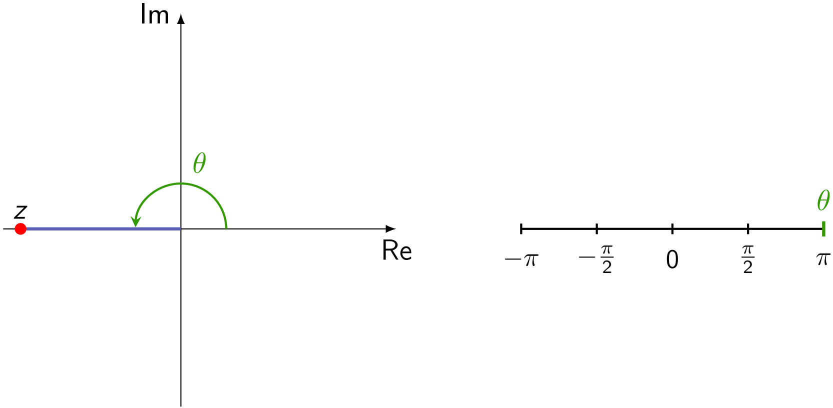

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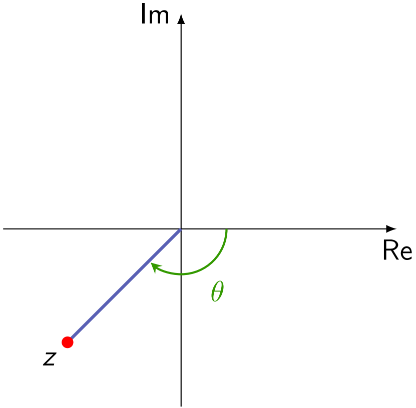

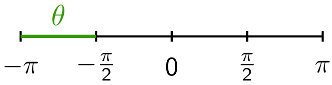

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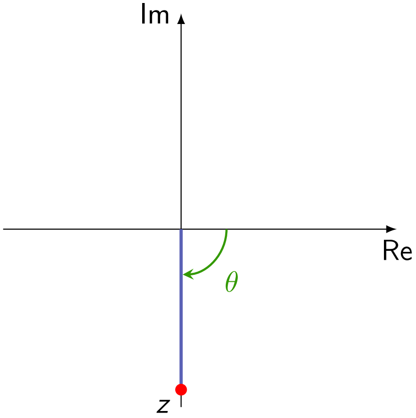

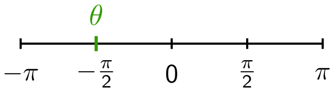

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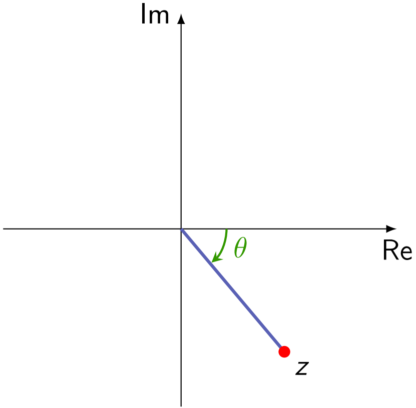

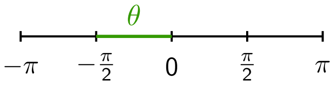

Example

Plot $1 + i$ on an Argand diagram and find its modulus and principal argument.

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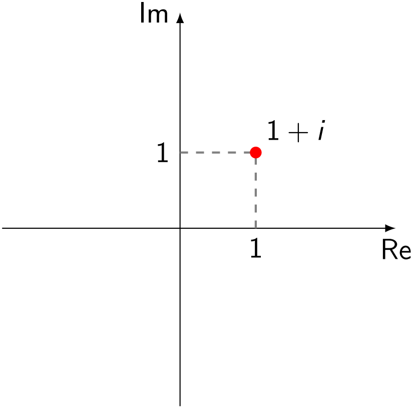

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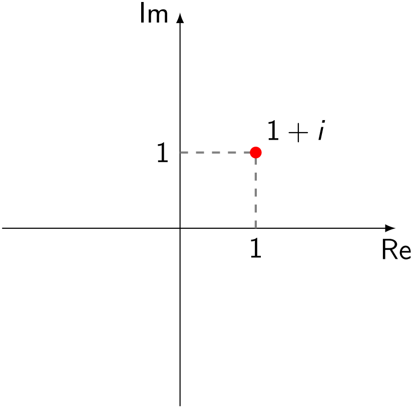

Modulus:

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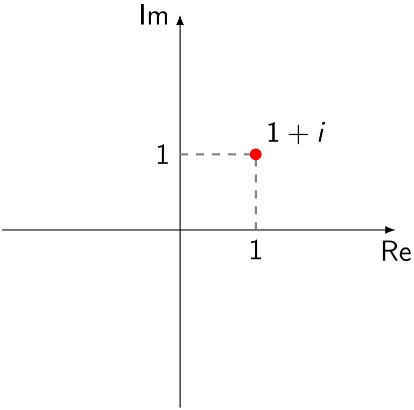

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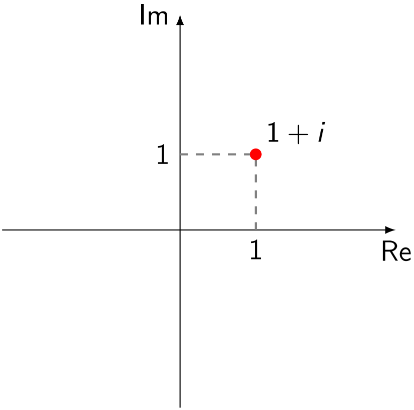

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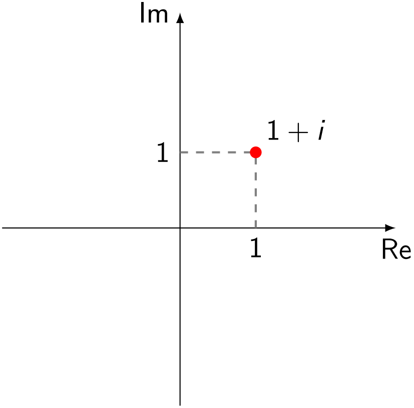

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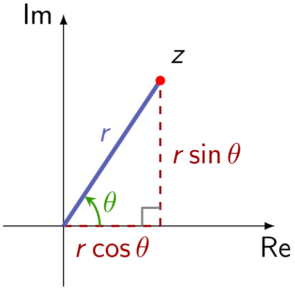
So $\operatorname{Arg}(1 + i) = \dfrac{\pi}{4}$.

Polar form

If $|z| = r$ and $\arg(z) = \theta$, then $\quad x = r\cos\theta \quad$ and $\quad y = r\sin\theta$.



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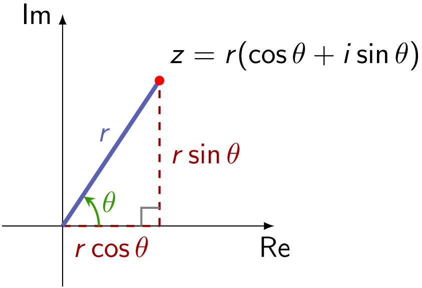

So for $z = x + iy$, we have

$$z = r(\cos\theta + i\sin\theta).$$

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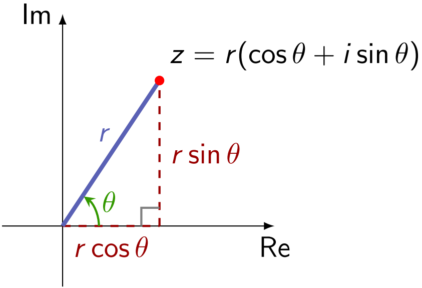

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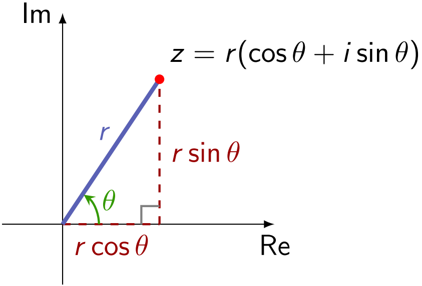

So for $z = x + iy$, we have

$$z = r(\cos\theta + i\sin\theta).$$

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Note that r must always be non-negative.

Examples

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(a) $1 + i$

(b) $-1 + \sqrt{3}i$

(c) $-3 - 3i$

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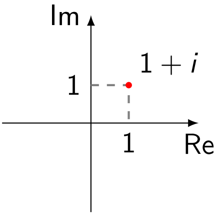

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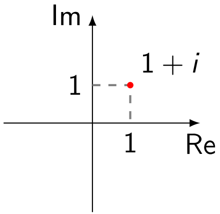

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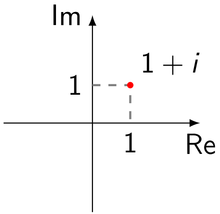

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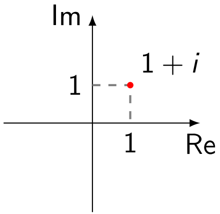

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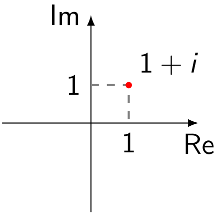

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$$1+i = \sqrt{2}\left(\cos\frac{\pi}{4} + i\sin\frac{\pi}{4}\right)$$

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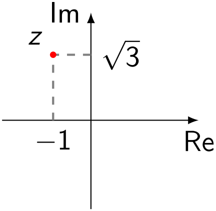

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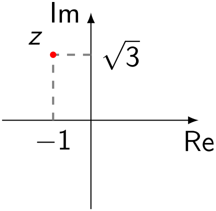

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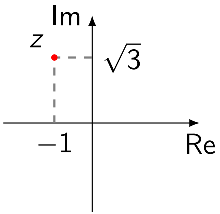

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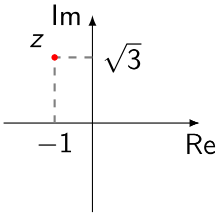

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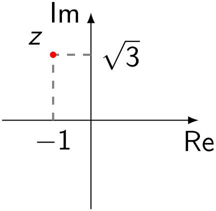

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$$-1+\sqrt{3}i = 2\left(\cos\frac{2\pi}{3} + i\sin\frac{2\pi}{3}\right)$$

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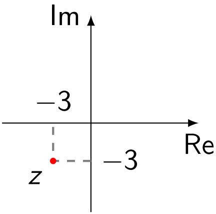

Example

Plot each of the following complex numbers on an Argand diagram and find its polar form.

(a) $1 + i$

(b) $-1 + \sqrt{3}i$

(c) $-3 - 3i$

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(e) $4i$

(f) 5

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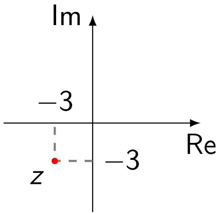

$$|z| = \sqrt{(-3)^2 + (-3)^2} = 3\sqrt{2}$$

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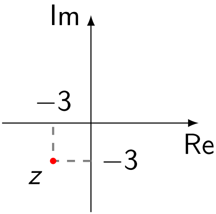

$$|z| = \sqrt{(-3)^2 + (-3)^2} = 3\sqrt{2}$$

$$\tan(\mathrm{Arg}(z)) = \tfrac{-3}{-3} = 1,$$

and $-\pi < \mathrm{Arg}(z) < -\dfrac{\pi}{2}$.

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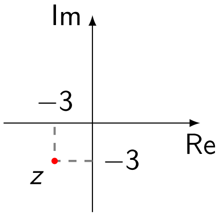

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So $\operatorname{Arg}(z) = -\dfrac{3\pi}{4}$.

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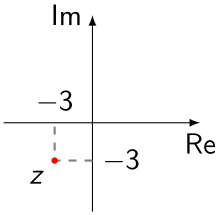

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So $\text{Arg}(z) = -\dfrac{3\pi}{4}$.

$$-3+-3i = 3\sqrt{2}\left(\cos\left(-\frac{3\pi}{4}\right) + i\sin\left(-\frac{3\pi}{4}\right)\right)$$

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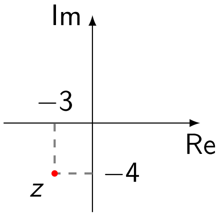

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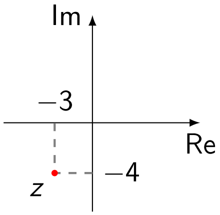

$$|z| = \sqrt{(-3)^2 + (-4)^2} = 5$$

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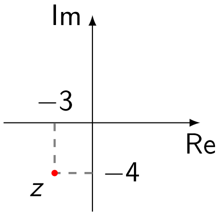

$$|z| = \sqrt{(-3)^2 + (-4)^2} = 5$$

$$\tan(\mathrm{Arg}(z)) = \tfrac{-4}{-3} = \tfrac{4}{3},$$

$$\text{and } -\pi < \mathrm{Arg}(z) < -\frac{\pi}{2}.$$

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Plot each of the following complex numbers on an Argand diagram and find its polar form.

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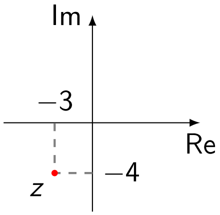

$$|z| = \sqrt{(-3)^2 + (-4)^2} = 5$$

$\tan(\mathrm{Arg}(z)) = \frac{-4}{-3} = \frac{4}{3}$,

and $-\pi < \mathrm{Arg}(z) < -\dfrac{\pi}{2}$.

So $\mathrm{Arg}(z) = -\pi + \tan^{-1}\left(\dfrac{4}{3}\right)$.

Examples

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Plot each of the following complex numbers on an Argand diagram and find its polar form.

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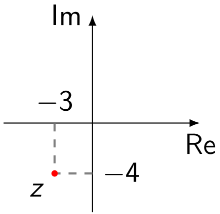

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So $\mathrm{Arg}(z) = -\pi + \tan^{-1}\left(\dfrac{4}{3}\right)$.

$$-3 + -4i = 5\left(\cos\alpha + i\sin\alpha\right),$$

where $\alpha = -\pi + \tan^{-1}\left(\dfrac{4}{3}\right)$

Examples

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Plot each of the following complex numbers on an Argand diagram and find its polar form.

(a) $1+i$

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Plot each of the following complex numbers on an Argand diagram and find its polar form.

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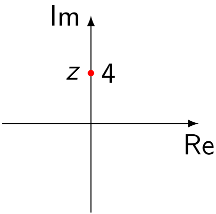

Example

Plot each of the following complex numbers on an Argand diagram and find its polar form.

(a) $1 + i$
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(c) $-3 - 3i$
(d) $-3 - 4i$
(e) $4i$
(f) 5
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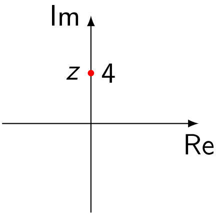

$|z| = 4$

Examples

Example

Plot each of the following complex numbers on an Argand diagram and find its polar form.

(a) $1+i$
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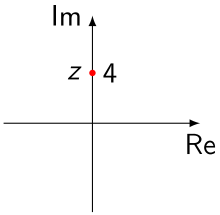
(h) 0



$$|z| = 4$$

$$\text{Arg}(z) = \frac{\pi}{2}$$

Examples

Example

Plot each of the following complex numbers on an Argand diagram and find its polar form.

(a) $1+i$
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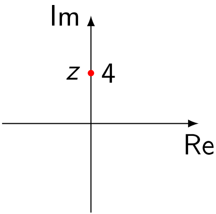

$$|z| = 4$$

$$\operatorname{Arg}(z) = \frac{\pi}{2}$$

$$4i = 4\left(\cos\frac{\pi}{2} + i\sin\frac{\pi}{2}\right)$$

Examples

Example

Plot each of the following complex numbers on an Argand diagram and find its polar form.

(a) $1+i$

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(c) $-3-3i$

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Plot each of the following complex numbers on an Argand diagram and find its polar form.

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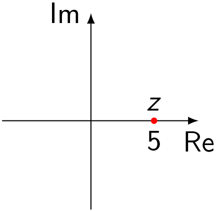

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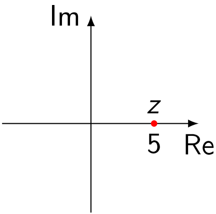

$|z| = 5$

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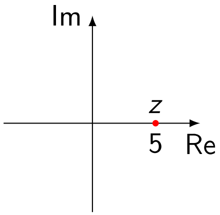

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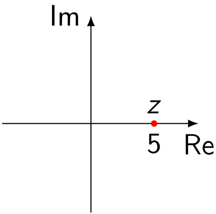

$|z| = 5$

$\text{Arg}(z) = 0$

$$5 = 5\,(\cos 0 + i \sin 0)$$

Examples

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Plot each of the following complex numbers on an Argand diagram and find its polar form.

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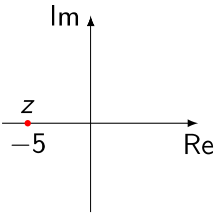

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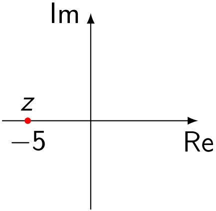

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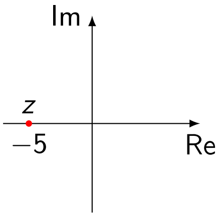

$|z| = 5$

$\text{Arg}(z) = \pi$

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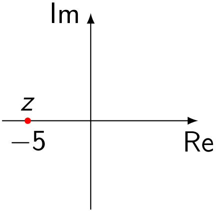

$$|z| = 5$$

$$\operatorname{Arg}(z) = \pi$$

$$-5 = 5\left(\cos\pi + i\sin\pi\right)$$

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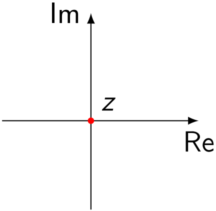

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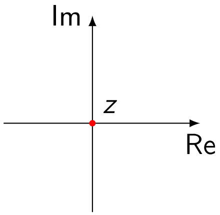

$|z| = 0$

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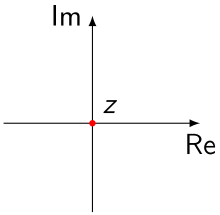

$|z| = 0$

$\operatorname{Arg}(z)$ is undefined

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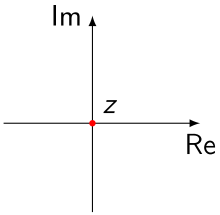

$|z| = 0$

$\mathrm{Arg}(z)$ is undefined

0 has no standard polar form.

Examples

Example

Sketch $z = \sqrt{18}\left(\cos\left(\frac{\pi}{4}\right) + i\sin\left(\frac{\pi}{4}\right)\right)$ in the complex plane and write z in Cartesian form.

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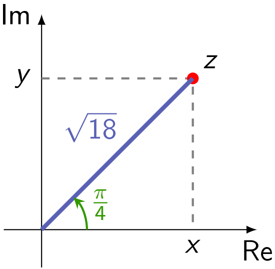

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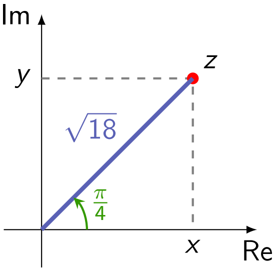

$$z = \sqrt{18}\cos\left(\frac{\pi}{4}\right) + \sqrt{18}i\sin\left(\frac{\pi}{4}\right)$$

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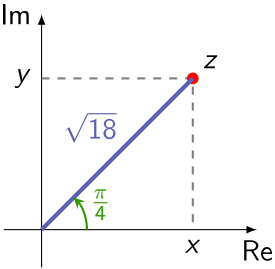
Sketch $z = \sqrt{18}\left(\cos\left(\frac{\pi}{4}\right) + i\sin\left(\frac{\pi}{4}\right)\right)$ in the complex plane and write z in Cartesian form.

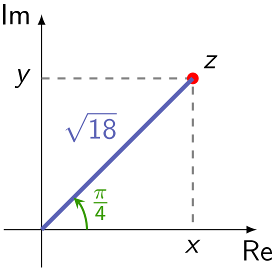


$$\begin{aligned} z &= \sqrt{18}\cos\left(\tfrac{\pi}{4}\right) + \sqrt{18}i\sin\left(\tfrac{\pi}{4}\right) \\ &= \sqrt{18} \times \frac{1}{\sqrt{2}} + \sqrt{18}i \times \frac{1}{\sqrt{2}} \end{aligned}$$

Examples

Example

Sketch $z = \sqrt{18}\left(\cos\left(\frac{\pi}{4}\right) + i\sin\left(\frac{\pi}{4}\right)\right)$ in the complex plane and write z in Cartesian form.



$$
\begin{aligned}
z &= \sqrt{18}\cos\left(\frac{\pi}{4}\right) + \sqrt{18}i\sin\left(\frac{\pi}{4}\right) \\
&= \sqrt{18} \times \frac{1}{\sqrt{2}} + \sqrt{18}i \times \frac{1}{\sqrt{2}} \\
&= 3 + 3i
\end{aligned}
$$

Examples

Example

Sketch $z = 8\left(\cos\left(-\frac{\pi}{6}\right) + i\sin\left(-\frac{\pi}{6}\right)\right)$ in the complex plane and write z in Cartesian form.

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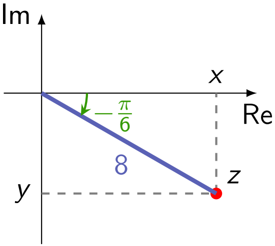
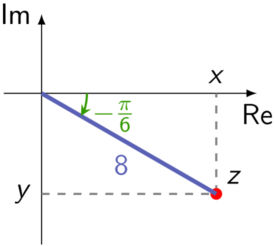
Sketch $z = 8\left(\cos\left(-\frac{\pi}{6}\right) + i\sin\left(-\frac{\pi}{6}\right)\right)$ in the complex plane and write z in Cartesian form.



Example

Sketch $z = 8\left(\cos\left(-\frac{\pi}{6}\right) + i\sin\left(-\frac{\pi}{6}\right)\right)$ in the complex plane and write z in Cartesian form.

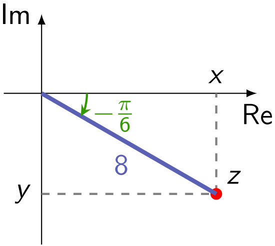


$$z = 8\cos\left(-\frac{\pi}{6}\right) + 8i\sin\left(-\frac{\pi}{6}\right)$$

Examples

Example

Sketch $z = 8\left(\cos\left(-\frac{\pi}{6}\right) + i\sin\left(-\frac{\pi}{6}\right)\right)$ in the complex plane and write z in Cartesian form.



$$\begin{aligned} z &= 8\cos\left(-\tfrac{\pi}{6}\right) + 8i\sin\left(-\tfrac{\pi}{6}\right) \\ &= 8 \times \tfrac{\sqrt{3}}{2} + 8i \times -\tfrac{1}{2} \end{aligned}$$

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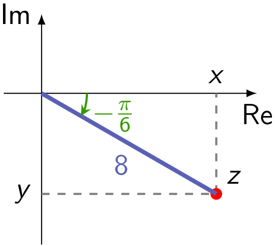

$$\begin{aligned} z &= 8\cos\left(-\frac{\pi}{6}\right) + 8i\sin\left(-\frac{\pi}{6}\right) \\ &= 8 \times \frac{\sqrt{3}}{2} + 8i \times -\frac{1}{2} \\ &= 4\sqrt{3} - 4i \end{aligned}$$

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Find the polar form of $w = -7\left(\sin\left(-\frac{\pi}{3}\right) + i\cos\left(-\frac{\pi}{3}\right)\right)$.

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w &= -7\left(\sin\left(-\frac{\pi}{3}\right) + i\cos\left(-\frac{\pi}{3}\right)\right) \\
&= -7\left(-\frac{\sqrt{3}}{2} + i\frac{1}{2}\right) \\
&= 7\left(\frac{\sqrt{3}}{2} - i\frac{1}{2}\right)
\end{aligned}$$

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$$\begin{aligned} w &= -7\left(\sin\left(-\frac{\pi}{3}\right) + i\cos\left(-\frac{\pi}{3}\right)\right) \\ &= -7\left(-\frac{\sqrt{3}}{2} + i\frac{1}{2}\right) \\ &= 7\left(\frac{\sqrt{3}}{2} - i\frac{1}{2}\right) \\ &= 7\left(\cos\left(-\frac{\pi}{6}\right) + i\sin\left(-\frac{\pi}{6}\right)\right) \end{aligned}$$