

# Quantum Workforce Development

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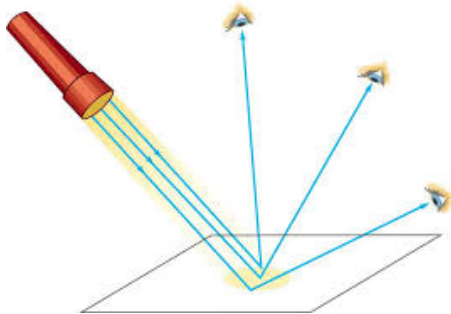
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# Geometric Optics



# Ray Nature of Light

The word "ray" means a straight line that originates at some point.

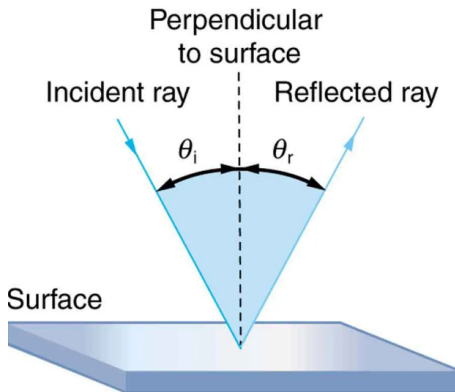


The part of optics dealing with the ray aspect of light is called "geometric optics."



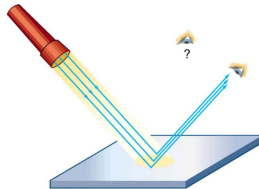
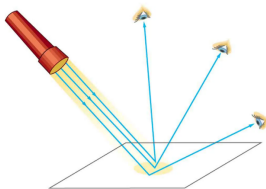
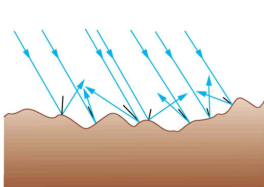
# Reflection

The angle of reflection equals the angle of incidence





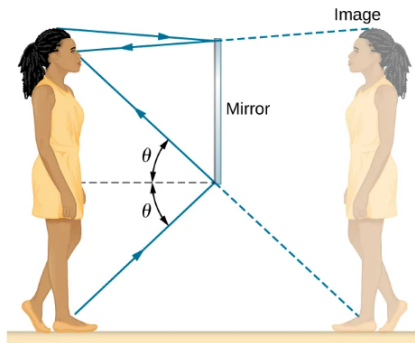
# Rough vs Smooth Surfaces





# Mirrors and Virtual Images

When we see ourselves in a mirror, it appears that our image is actually behind the mirror.

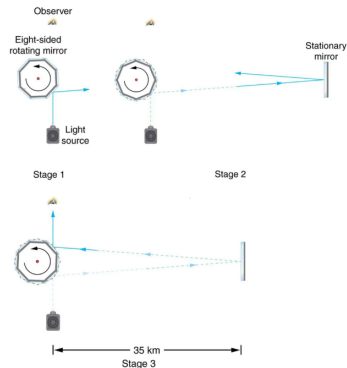




# Speed of Light

- In 1676, Danish astronomer Ole Roemer noted the change in orbital period of Jupiter's moons depending of if the earth was moving towards or away from Jupiter. He as able to calculate speed of light to be  $2.26 \times 10^8 (\frac{m}{s})$ .
- In 1887, American physicist Albert Michelson used a rotating mirror to get a more precise measurement of the speed of light.
- Today, the speed of light is known as:

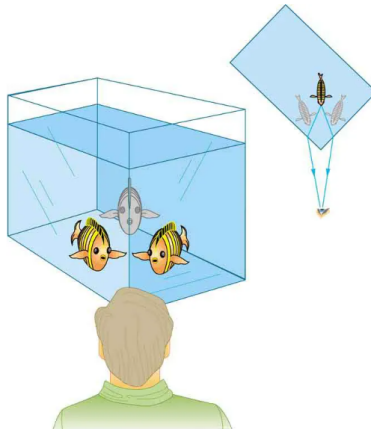
$$c = 2.9979245810^8 (\frac{m}{s}).$$





# Refraction

The changing of a light ray's direction (loosely called bending) when it passes through variations in matter is called refraction.







# Index of Refraction

The speed of flight depends strongly on the type of material. We define the index of refraction ( $n$ ) as

$$n = \frac{c}{v}$$

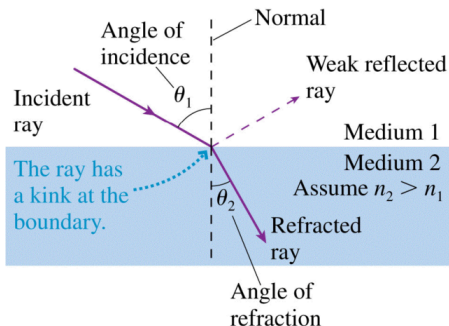
where  $v$  is the speed of light in the material and  $c$  is the speed of light in a vacuum.

**TABLE 23.1** Indices of refraction

Medium	$n$
Vacuum	1.00 exactly
Air (actual)	1.0003
Air (accepted)	1.00
Water	1.33
Ethyl alcohol	1.36
Oil	1.46
Glass (typical)	1.50
Polystyrene plastic	1.59
Cubic zirconia	2.18
Diamond	2.41
Silicon (infrared)	3.50



# Snell's Law



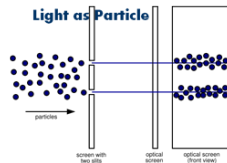
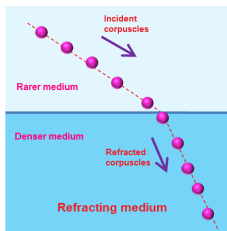
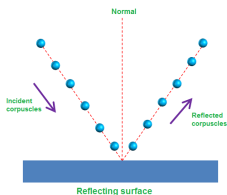
$$\text{Snell's Law: } n_1 \sin \Theta_1 = n_2 \sin \Theta_2$$

Light - a particle or a wave



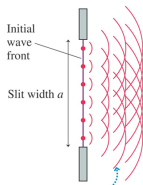
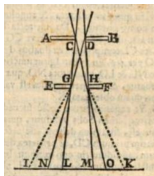
# Corpuscular Theory of Light

In 1675, Sir Isaac Newton hypothesized that light was made up of corpuscles (small particles) with the size/mass of the corresponding to different colors.





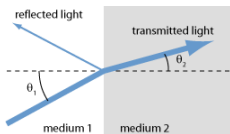
# Huygens Principle



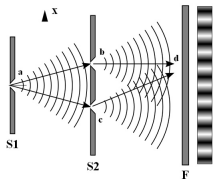
- Francesco Maria Grimaldi (mid-1600's) made accurate observations of the diffraction of light.
- In 1678, Christian Huygens, in order to explain the diffraction of light, proposed that every point on a wavefront (of light) is a wavelet that spreads.



# Fresnel and Young



- In 1815, Augustin Jean Fresnel developed the laws of reflection and refraction.



- And, in 1817, Thomas Young calculated the wavelength of light



# Maxwell's Equations: Electric $\vec{E}$ and Magnetic $\vec{B}$ Fields

In 1864, James Clerk Maxwell predicted electromagnetic waves

- Gauss's Law:  $\nabla \cdot \vec{E} = \frac{\rho}{\epsilon_0}$ , where  $\rho$  is enclosed charge
- Gauss's Law for Magnets:  $\nabla \cdot \vec{B} = 0$
- Faraday's Law:  $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$
- Ampere's Law:  $\nabla \times \vec{B} = \mu_0 \vec{J} + \mu_0 \epsilon_0 \frac{\partial \vec{E}}{\partial t}$

where

$$\mu_0 = 4\pi * 10^{-7} \frac{F}{m} \text{ and } \epsilon_0 = 8.85 * 10^{-12} \frac{Nm^2}{C}$$

Maxwell noted that the speed of the electromagnetic wave is equal to the speed of light:

$$\frac{1}{\sqrt{\mu_0 \epsilon_0}} = \frac{1}{\sqrt{4\pi * 10^{-7} * 8.85 * 10^{-12}}} = 2.99 * 10^8 \frac{m}{s} = c$$

# Intro to Quantum Phenomenon



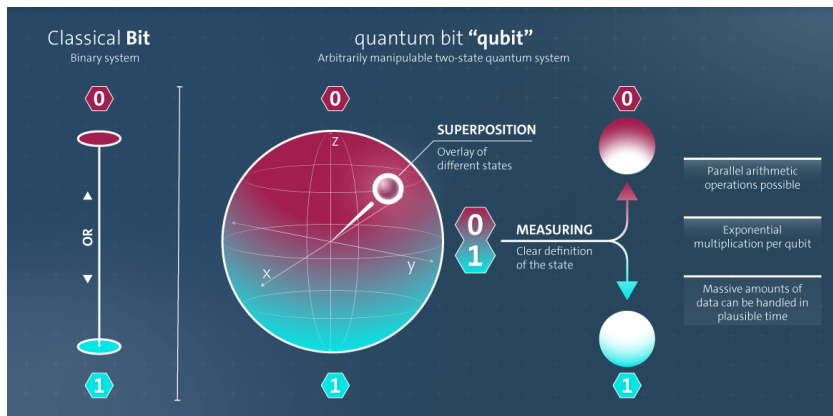


# Let there be light

# What is a Qubit



# Bit vs Qubit



# Quantum Computing



# Types of Quantum Computers

- Superconducting
- Photonic
- Neutral Atom
- Trapped Ion
- Quantum Dots
- Diamond Nitrogen Vacancies



# Quantum Computing: Superconducting

One of the most popular types of quantum computers is a superconducting qubit quantum computer. Usually made from superconducting materials, these quantum computers utilize tiny electrical circuits to produce and manipulate qubits. When using superconducting qubits, gate operations can be performed quickly.

Companies actively researching and manufacturing superconducting quantum computers include Google, IBM, IQM and Rigetti Computing to name just a few.



# Quantum Computing: Photonics

These types of quantum computers use photons (particles of light) to carry and process quantum information. For large-scale quantum computers, photonic qubits are a promising alternative to trapped ions and neutral atoms that require cryogenic or laser cooling.



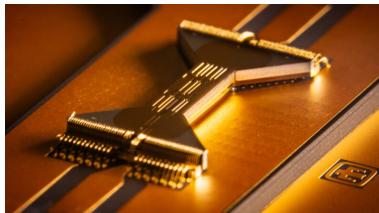
# Quantum Computing: Neutral Atom

Quantum computing based on neutral atoms involves atoms suspended in an ultrahigh vacuum by arrays of tightly focused laser beams called optical tweezers, though not all neutral atom companies use optical tweezers. Neutral atom quantum computers are less sensitive to stray electric fields, which makes them a good option for quantum processors.





# Trapped Ions



A trapped ion quantum computer involves using atoms or molecules with a net electrical charge known as “ions” that are trapped and manipulated using electric and magnetic fields to store and process quantum information. As trapped ions can be isolated from their environment, they are useful for precision measurements and other applications requiring high levels of stability and control. Also, the qubits can remain in a superposition state for a long time before becoming decoherent. Representing the trapped ions community of companies in the quantum space, we have Quantinuum (a company that came out of the merger between Cambridge Quantum Computing and Honeywell Quantum).



# Quantum Computing: Quantum Dots

A quantum dot quantum computer uses silicon qubits made up of pairs of quantum dots. In theory for quantum computers, such 'coupled' quantum dots could be used as robust quantum bits, or qubits.

Companies focused on this area include Diraq, Siquance and Quantum Motion.



# Quantum Computing: NV Diamond