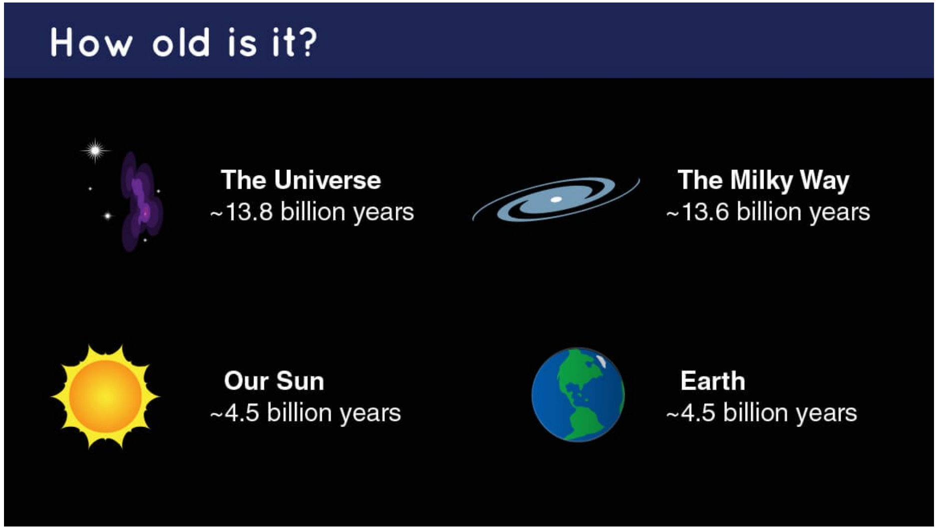
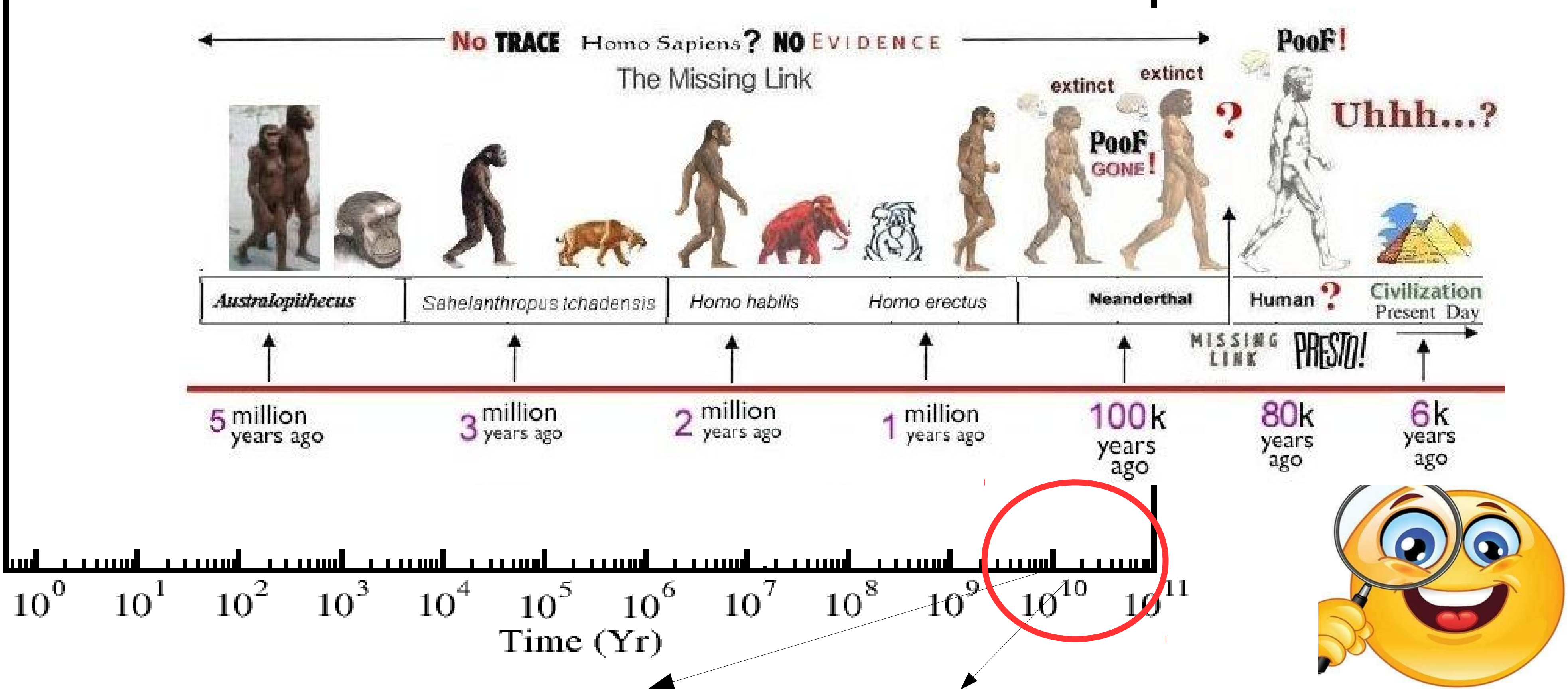
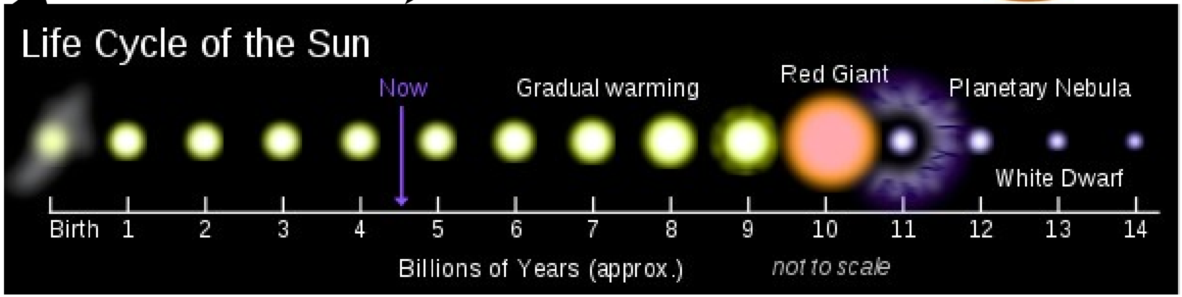
Trying to orient our brain about entire **time axis** of our unverse life time



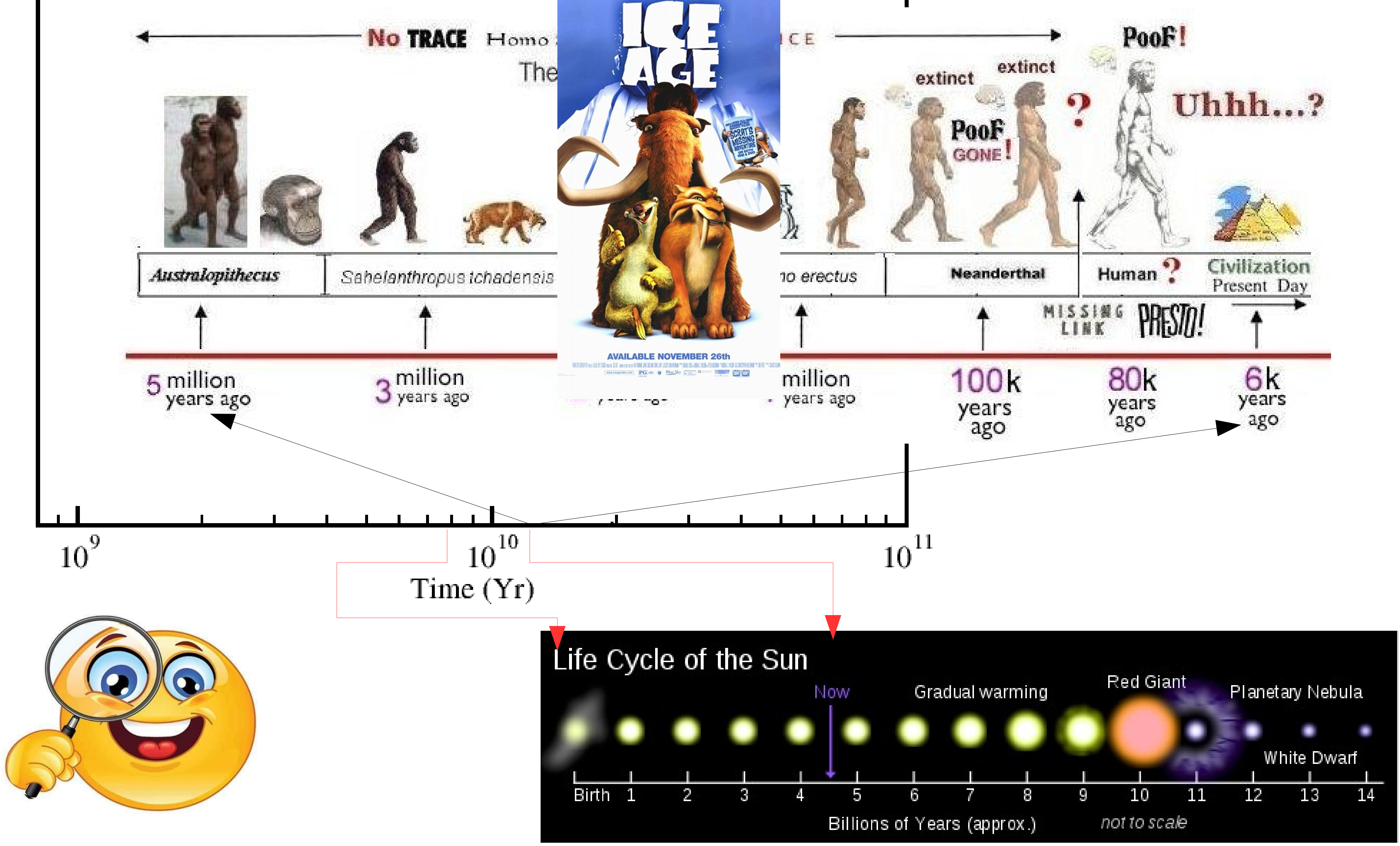
Number in words	*Number in figures*	*Number in standard form*	*Number written as a decimal*
One thousand	1,000	10^3	
Ten thousand	10,000	10^4	0.01 million
One hundred thousand	100,000	10^5	0.1 million
One million	1,000,000	10^6	
Ten million	10,000,000	10^7	0.01 billion
One hundred million	100,000,000	10^8	0.1 billion
One billion	1,000,000,000	10^9	
Ten billion	10,000,000,000	10^{10}	0.01 trillion
One hundred billion	100,000,000,000	10^{11}	0.1 trillion
One trillion	1,000,000,000,000	10^{12}	
One quadrillion	1,000,000,000,000,000	10^{15}	





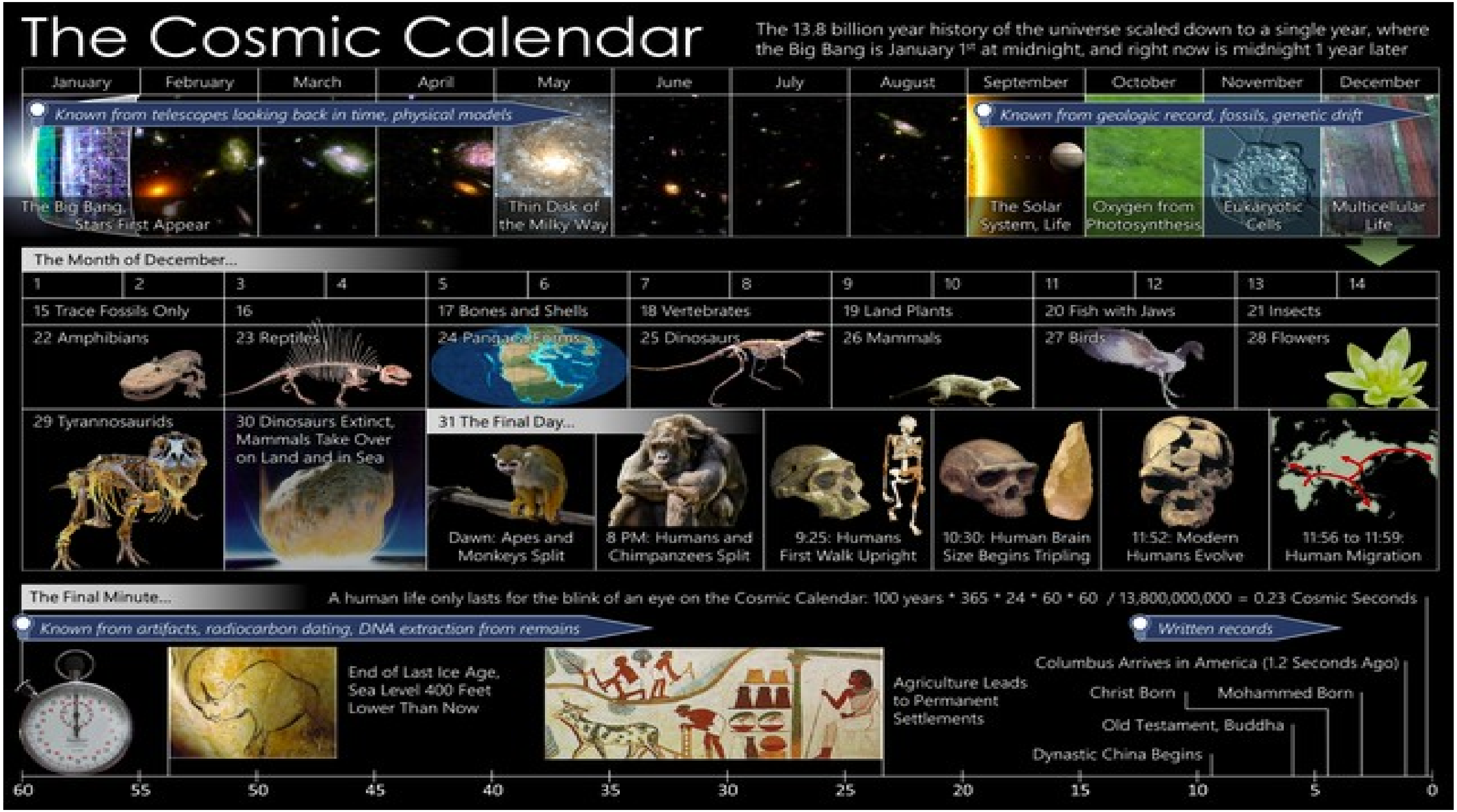
YouTube

https://www.youtube.com/watch?v=JgPwTA_o90s

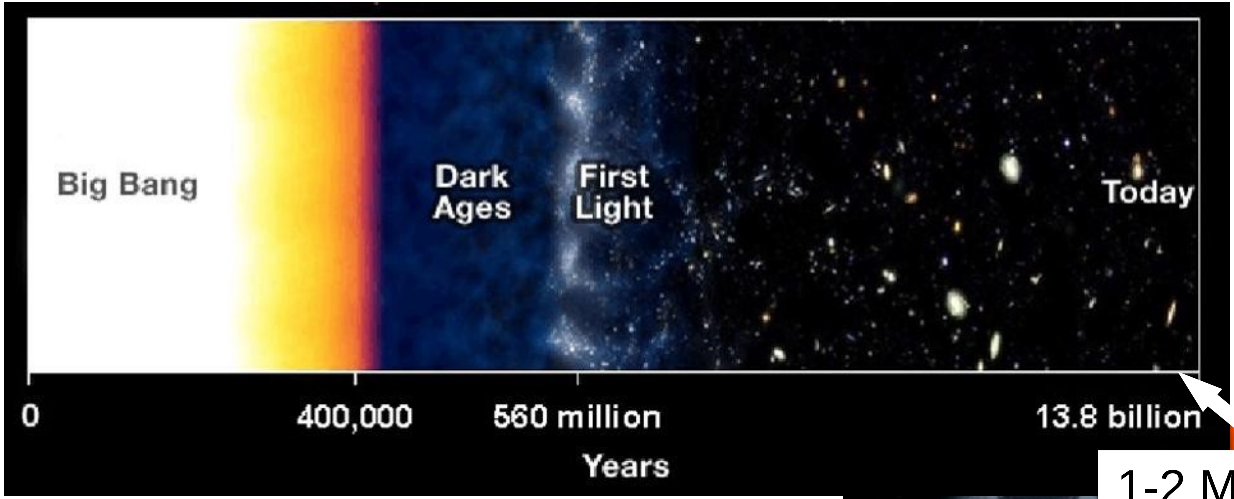


No TRACE
Homo
The
ICE
ICE AGE
SCRAT'S MISSING ADVENTURE
AVAILABLE NOVEMBER 26th
PooF!
extinct
extinct
PooF
GONE!
?
Uhhh...?
Australopithecus
Sahelanthropus tchadensis
o erectus
Neanderthal
Human ?
Civilization
Present Day
MISSING LINK
PRESTO!
5 million years ago
3 million years ago
million years ago
100k years ago
80k years ago
6k years ago
10^{9}
10^{10}
10^{11}
Time (Yr)
Life Cycle of the Sun
Now
Gradual warming
Red Giant
Planetary Nebula
White Dwarf
Birth 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Billions of Years (approx.)
not to scale

Wikipedia Link: https://en.wikipedia.org/wiki/Cosmic_Calendar



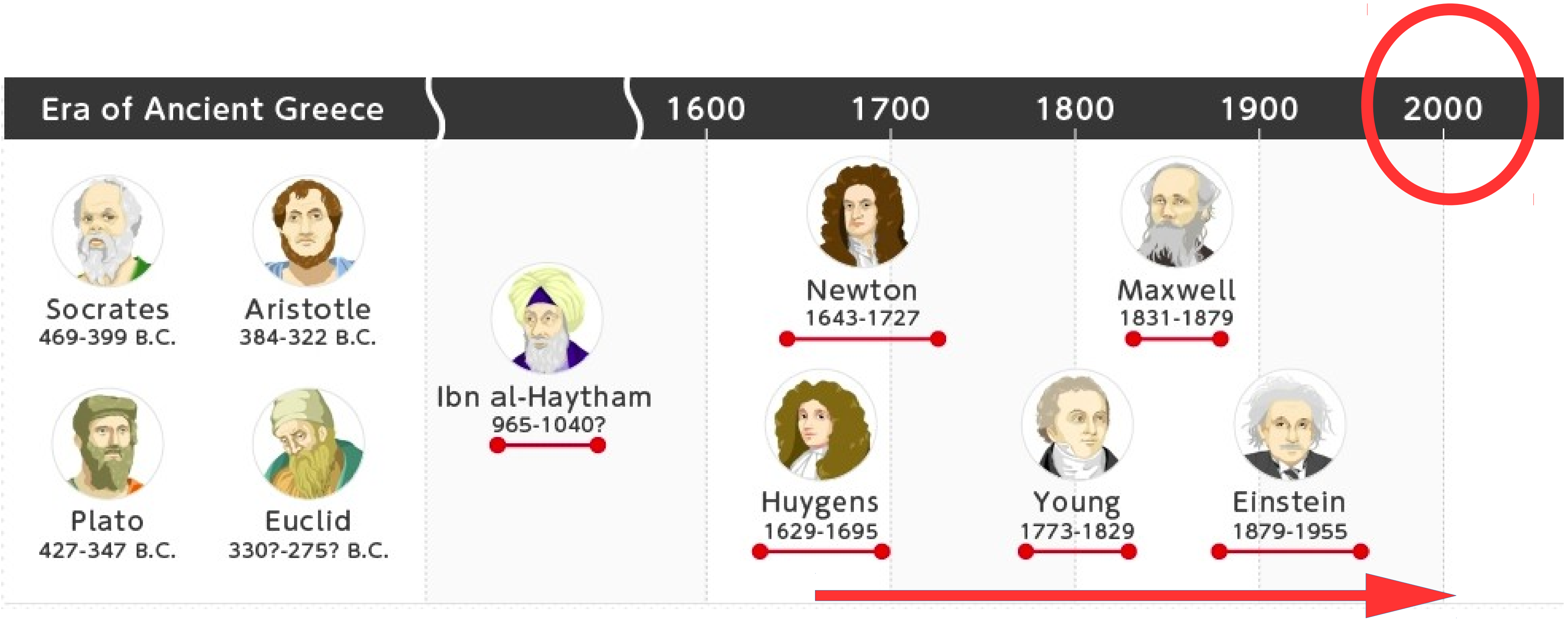
Ancient Light for Universe and Human history



1-2 Million years Ago

Duration when scientific thought on Light started

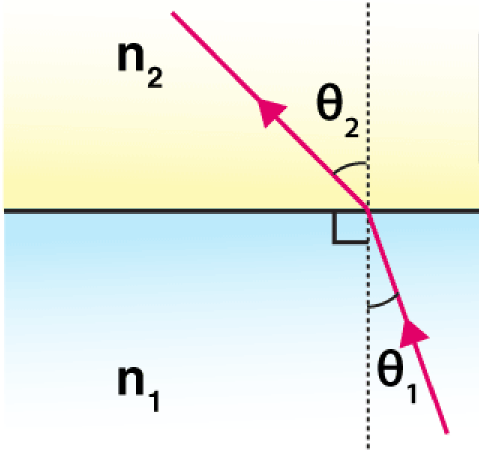
Photonics Timeline
(1960-Present)



Journey from Light to Photons

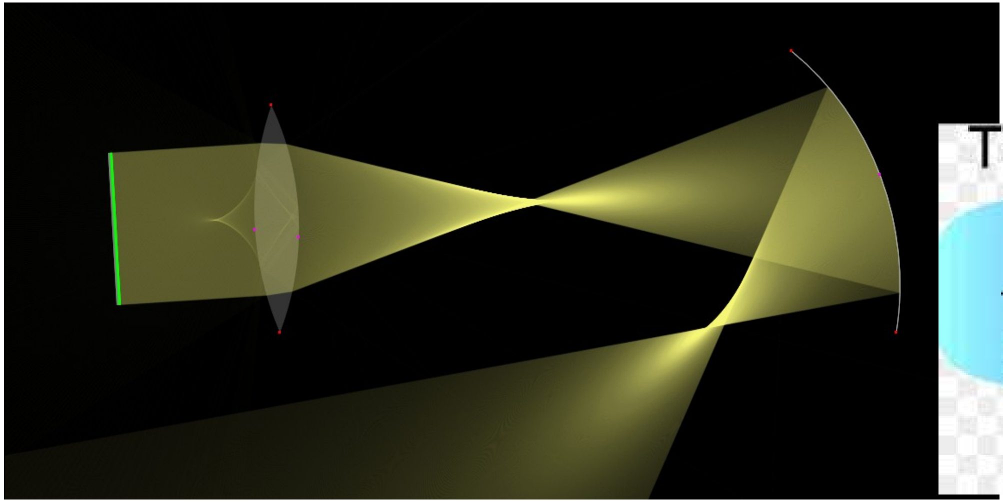
Link : https://photonterrace.net/en/photon/history/

What is light ? Ans: Just consider as Ray/something flowing. Just focus on its direction (Ray Optics/Geometrical Optics)



Snell's Law :
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

- Laws of Reflection
- Laws of Refraction : Snell's law (Willebrord Snellius 1580–1626)
- Fermat's principle (1607-65)

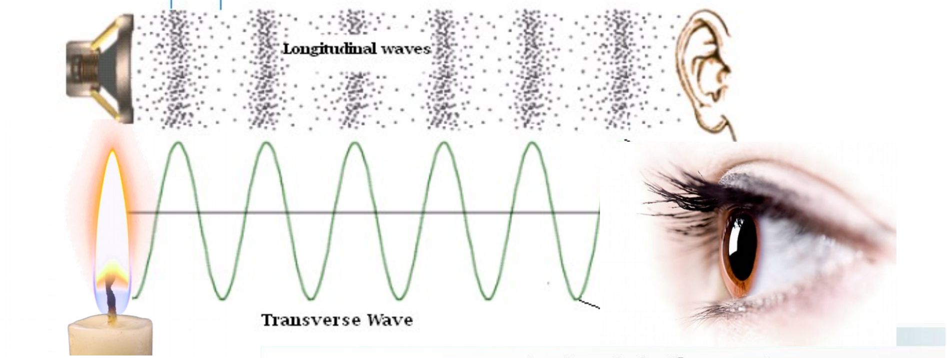


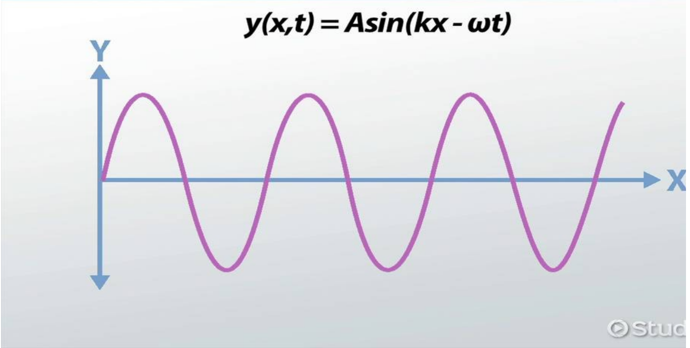
The lens forumula

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

f = focal length (m)
u = object distance (m)
v = image distance (m)

What is light ? Ans: It is a Wave. Just like Sound, **some quantity (??)** is fluctuating with time ans space (Physical Optics)





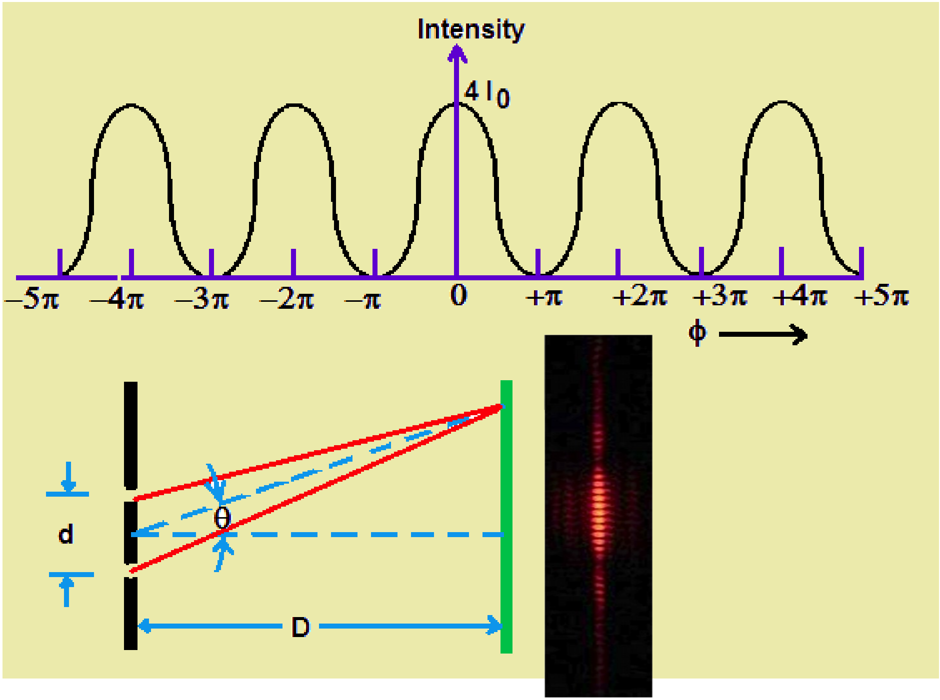
Amplitude A is constant with space x and time t

Christiaan Huygens
(1629 - 1695)

Thomas Young
(1773 - 1829)

Wave Optics
Diffraction & Interference

What is light ? Ans: It is a Wave. Just like Sound, **some quantity (??)** is fluctuating with time ans space (Physical Optics)



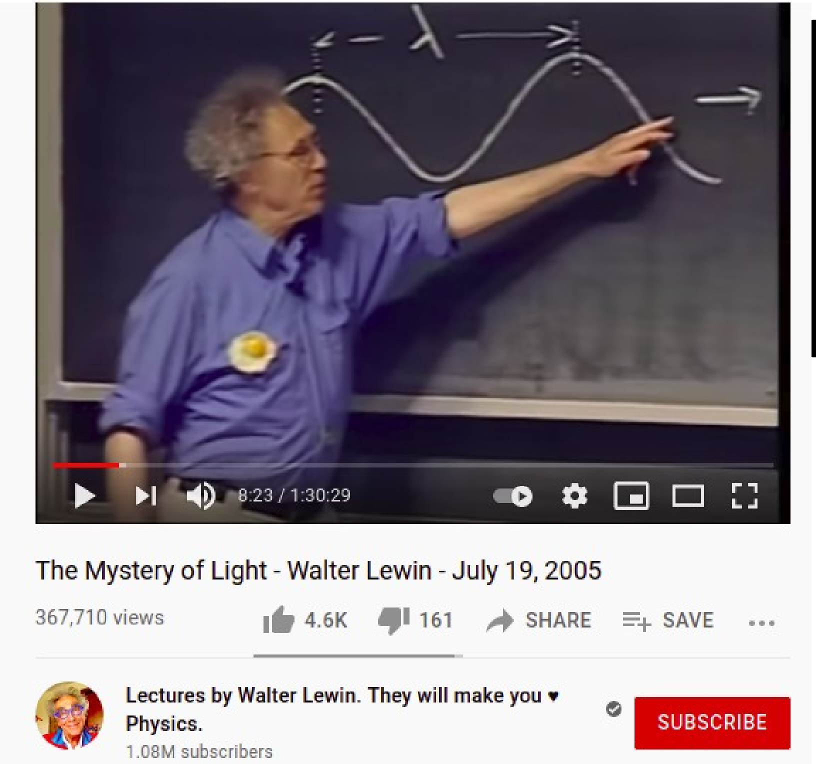
Christiaan Huygens
(1629 - 1695)

Thomas Young
(1773 - 1829)

If we make Amplitude A as afunction of space x

Wave Optics

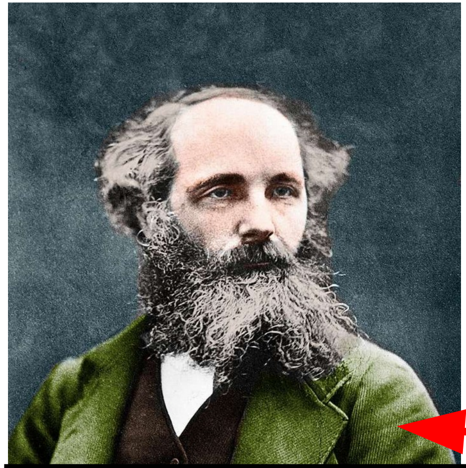
Diffraction & Interference



- https://www.youtube.com/watch?v=irpjwXpa4xU
- https://www.youtube.com/watch?v=WEMdxBKRXhE
- https://www.youtube.com/watch?v=LnJIZ_lwSBM

- https://www.youtube.com/watch?v=YY-dmu4YpBU
- https://www.youtube.com/watch?v=_LZzML_VQMA

What is light ? Which quantity is fluctuating? Ans: Interestingly the answer was hidden in the branch of Electricity & Magnetism.



James Clerk Maxwelle (1831-1879)

$$\nabla \bullet \mathrm{E} = \frac{\rho}{\epsilon_0}$$

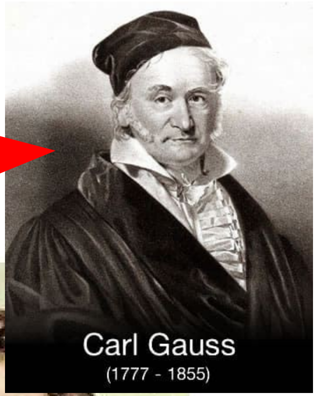
$$\nabla \bullet \mathrm{B} = 0$$

$$\nabla \times \mathrm{E} = -\frac{\partial \mathrm{B}}{\partial t}$$

$$\nabla \times \mathrm{B} = \mu_0 \left(\mathrm{J} + \epsilon_0 \frac{\partial \mathrm{E}}{\partial t} \right)$$

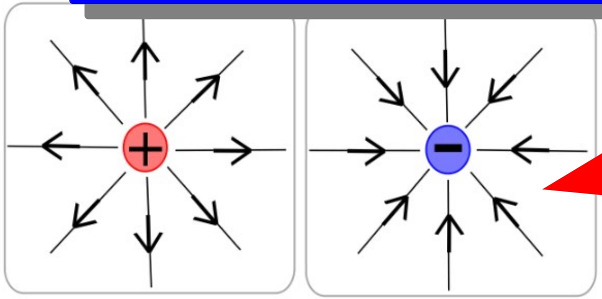
Michael Faraday (1791-1867)

Andre Marie Ampere (1755-1836)



Carl Gauss (1777 - 1855)

What is light ? Which quantity is fluctuating? Ans: Interestingly the answer was hidden in the branch of Electricity & Magnetism.

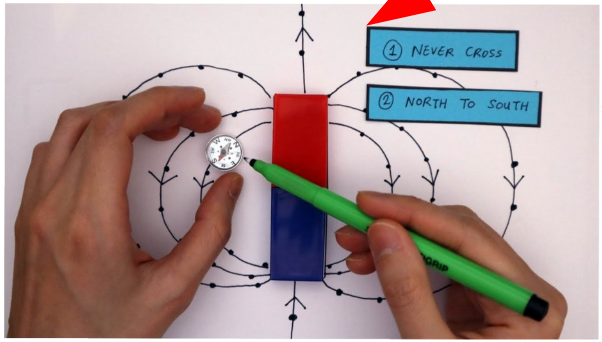


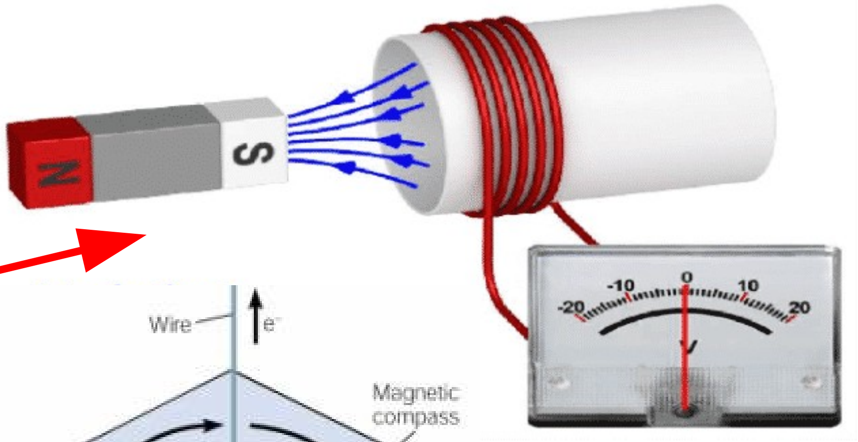
$$\nabla \cdot E = \frac{\rho}{\epsilon_0}$$

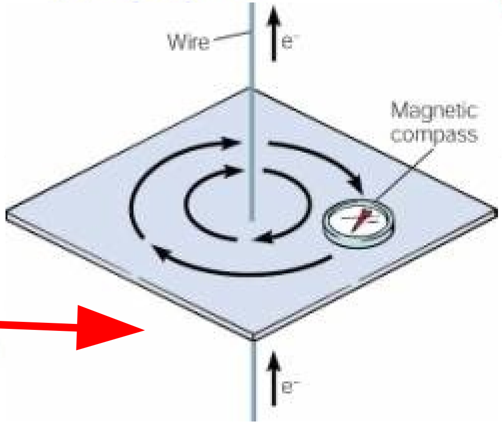
$$\nabla \cdot B = 0$$

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$\nabla \times B = \mu_0 \left(J + \epsilon_0 \frac{\partial E}{\partial t} \right)$$







What is light ? Ans: Light is fluctuating Electric & Magnetic field – An Electro-magnetic Wave

$$\nabla \bullet E = \cancel{\frac{\rho}{\epsilon_0}}$$

$$\nabla \bullet B = 0$$

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

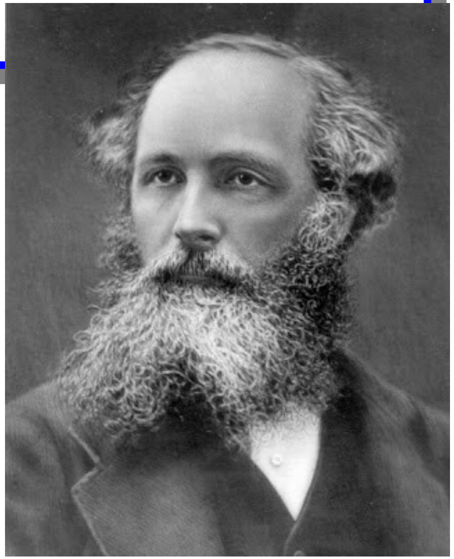
$$\nabla \times B = \cancel{\mu_0}\left(\cancel{\mathbf{J}+}\epsilon_0 \frac{\partial E}{\partial t}\right)$$

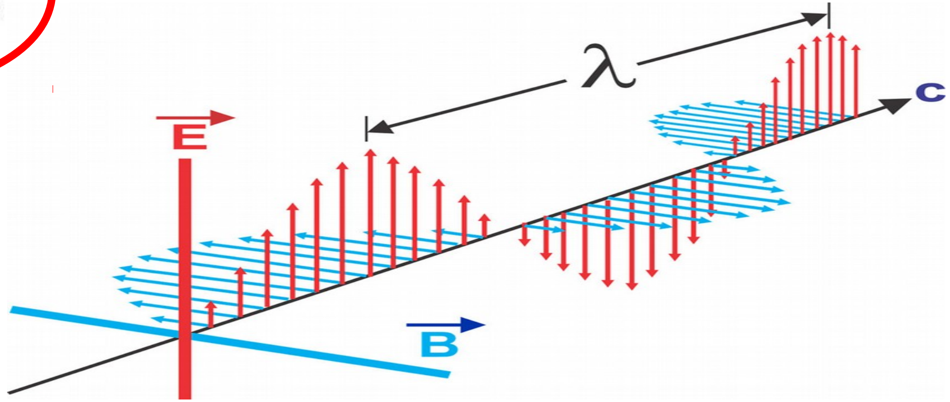
$$\left(v_{ph}^2 \nabla^2 - \frac{\partial^2}{\partial t^2}\right)\mathbf{E} = \mathbf{0}$$

$$\left(v_{ph}^2 \nabla^2 - \frac{\partial^2}{\partial t^2}\right)\mathbf{B} = \mathbf{0}$$

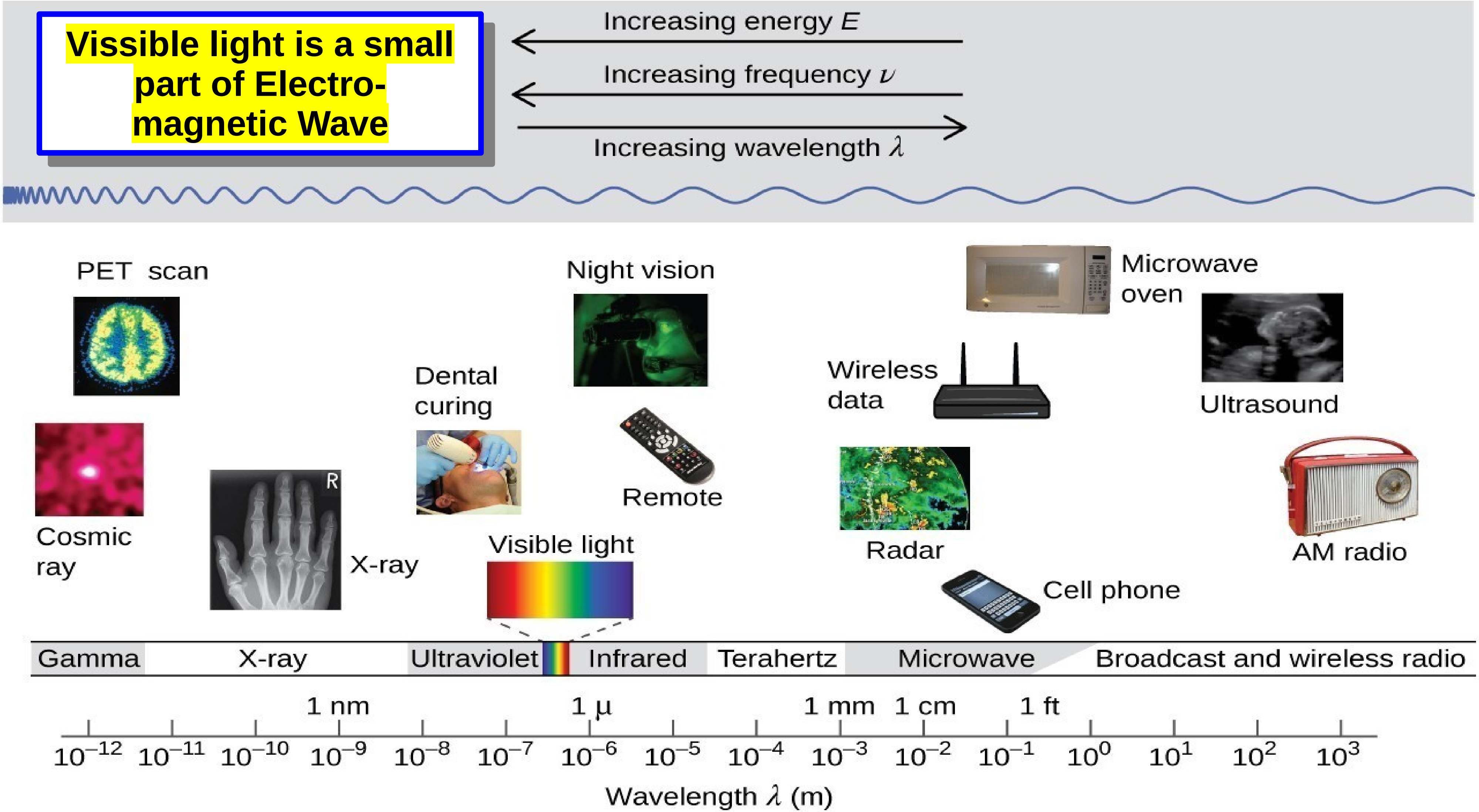
where

$$v_{ph} = \frac{1}{\sqrt{\mu\varepsilon}}$$

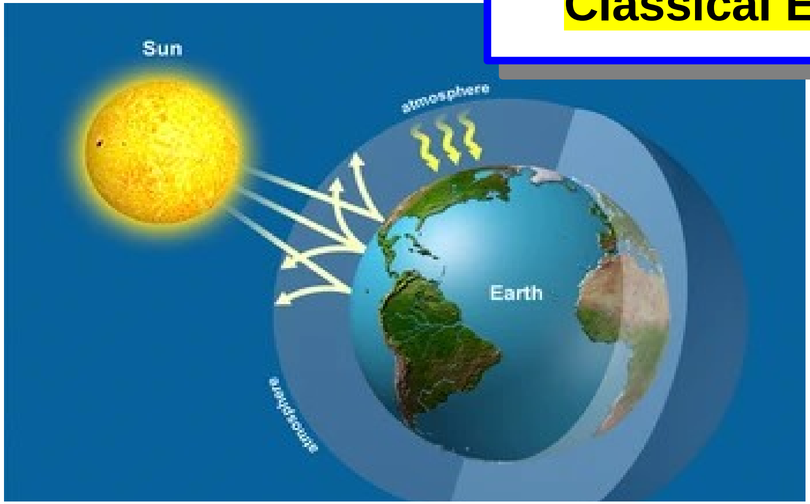


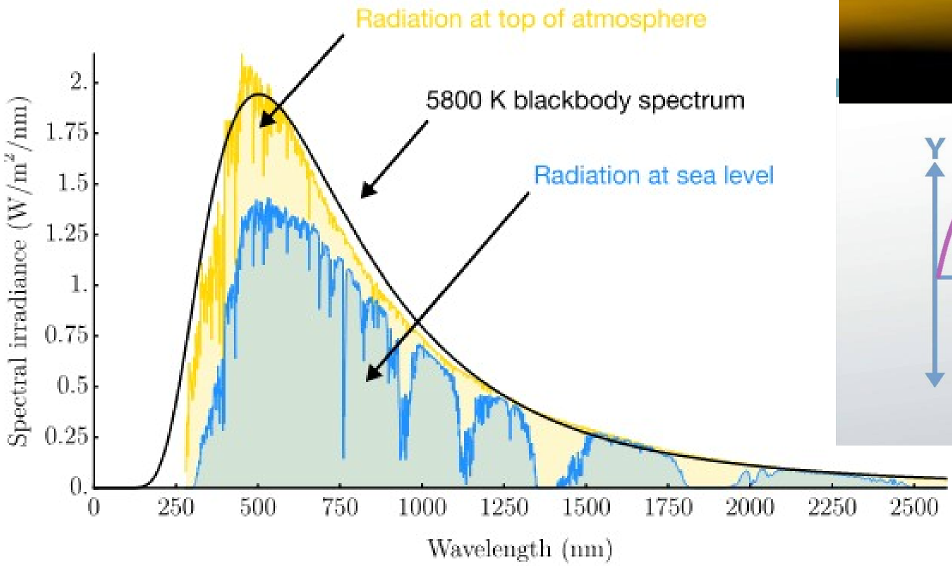


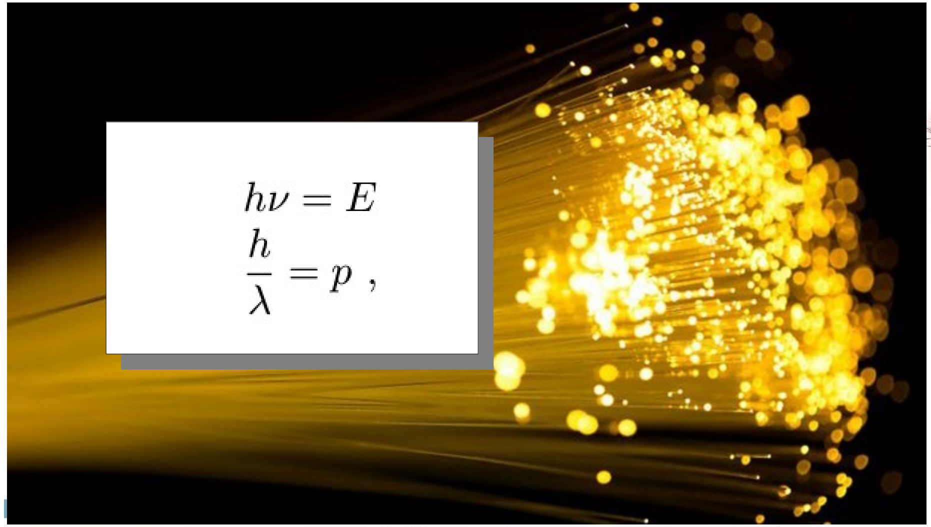
Vissible light is a small part of Electro-magnetic Wave



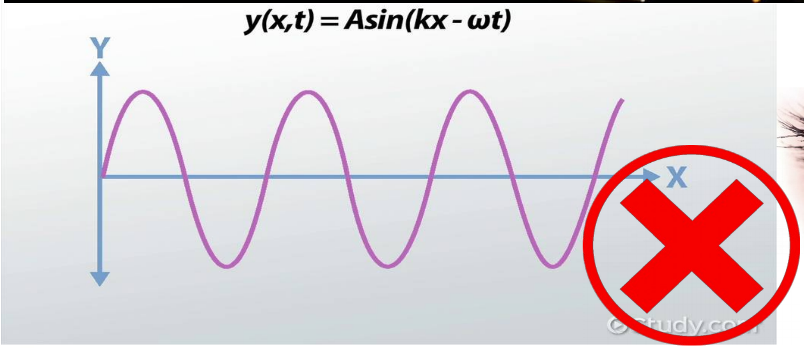
Classical EM Wave failed to explain Black Body Radiation







$$h\nu = E$$
$$\frac{h}{\lambda} = p\ ,$$



What is light ? Ans: Billions of photon particles with cpeed c

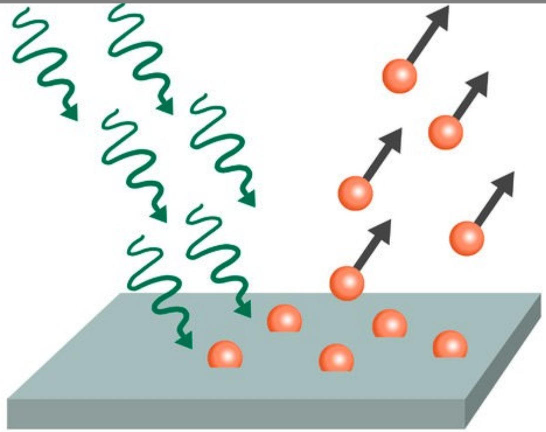
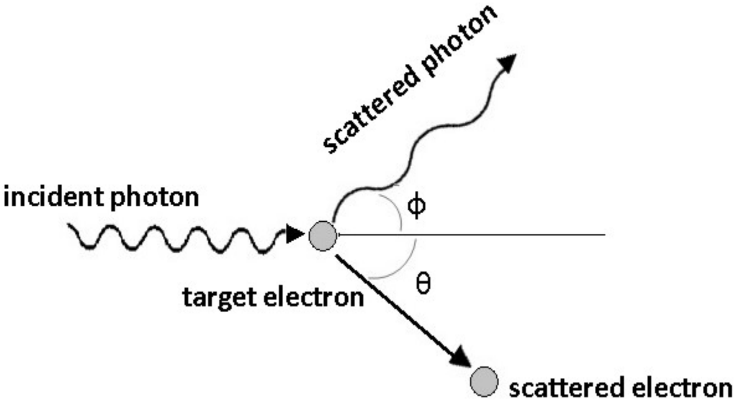
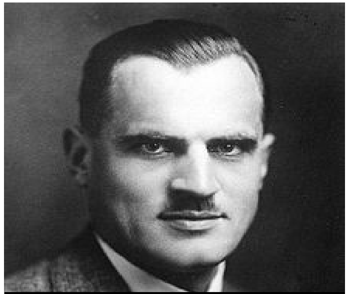


Photo electric effect

Albert Einstein
(1879-1955)

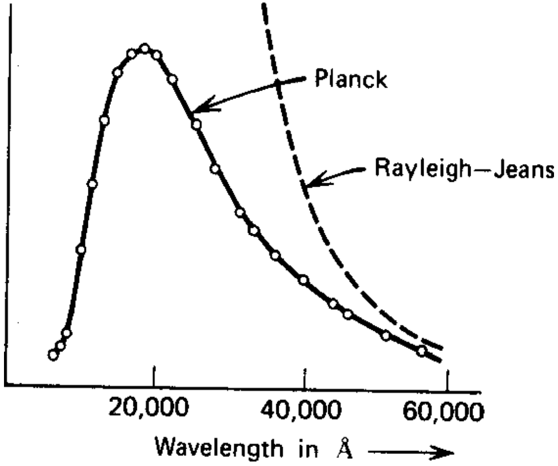


Compton Scattering



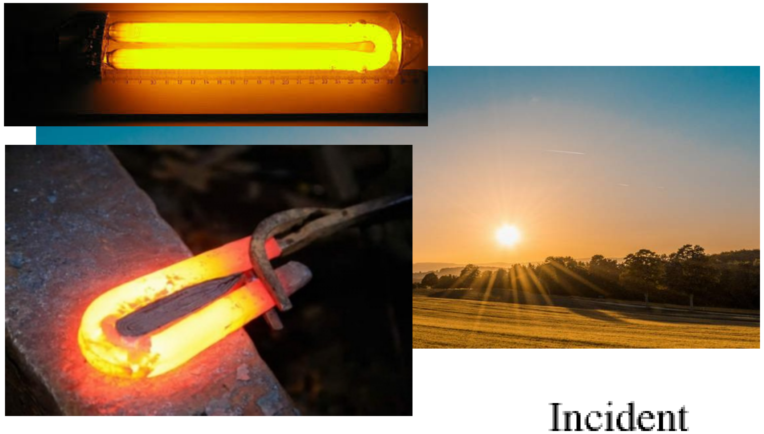
Arthur Compton
(1892-1962)

Black Body Radiation

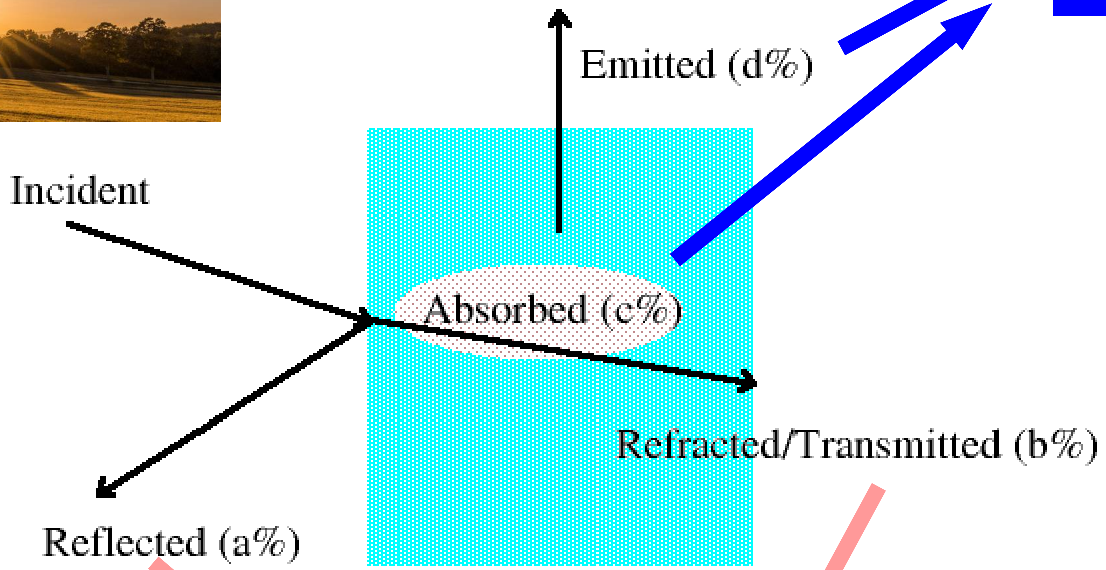


Max Planck
(1858-1947)

Black Body Radiation
(100% absorbtion or Emission)



Normal Radiation



Explanation from **Quantum Mechanics**

Explanation from **Classical picture**

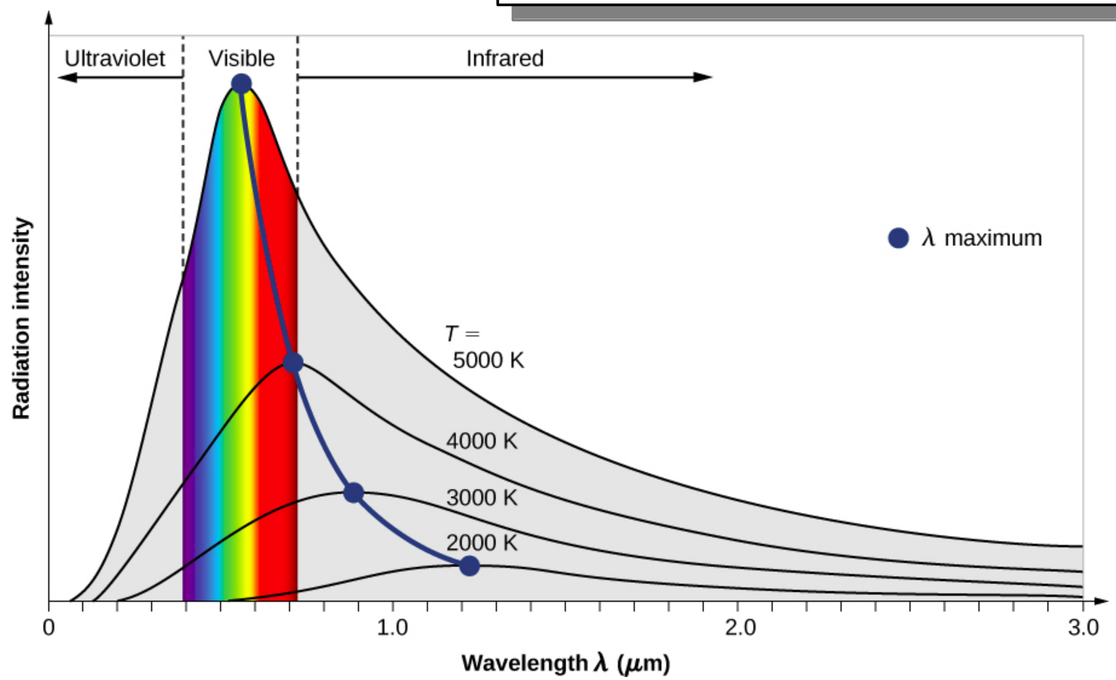
Black Body Radiation

Rayleigh-Jeans Law

$$\begin{aligned}\epsilon(\nu)d\nu &= \text{Density of stationary light} \times \text{Average energy} \\ &= 2\frac{4\pi\nu^2 d\nu}{c^3} \times 2\frac{1}{2}KT \\ \Rightarrow \epsilon(\lambda) &= \frac{8\pi KT}{\lambda^4}\,, \qquad (4)\end{aligned}$$

Wien's parametrization

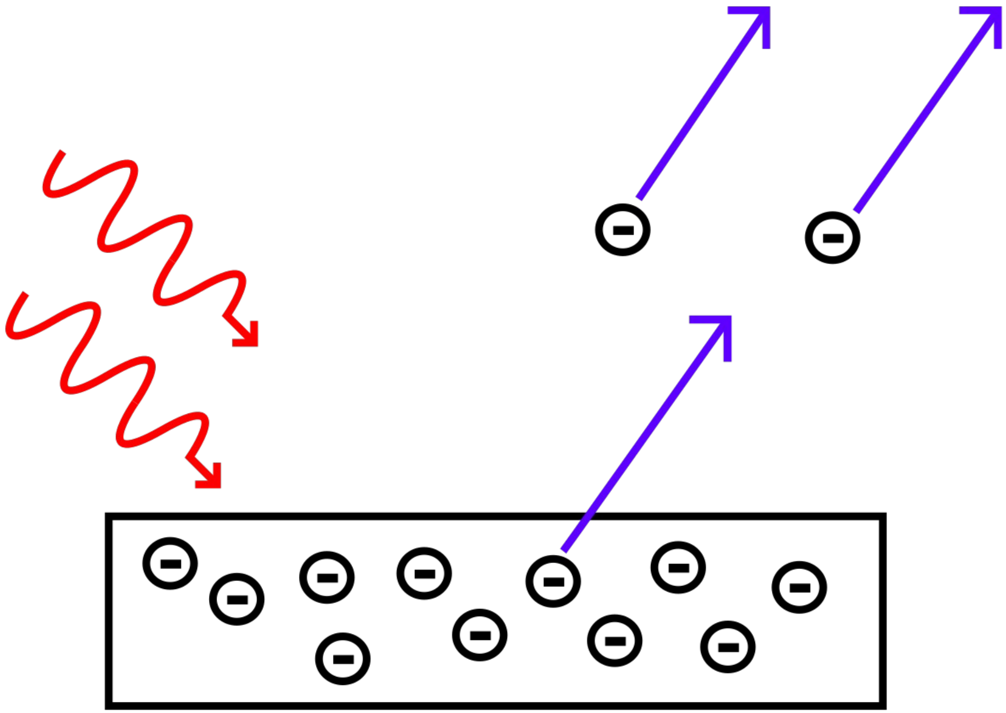
$$\epsilon(\lambda) = \frac{A}{\lambda^5} e^{-B/\lambda T}$$



Planck's Radiation Law

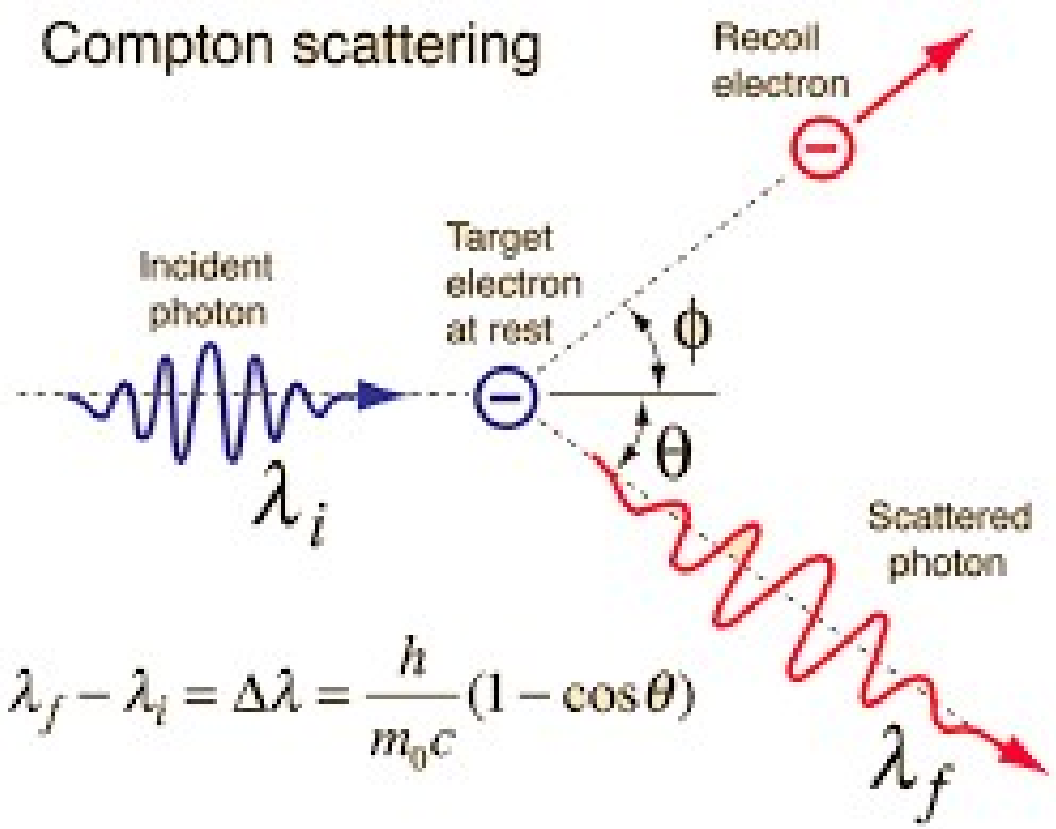
$$\begin{aligned}\epsilon(\nu)d\nu &= \text{Density of stationary light} \times \text{Average energy} \\ &= 2\frac{4\pi\nu^2 d\nu}{c^3} \times 2\frac{1}{2}KT \\ \Rightarrow \epsilon(\lambda) &= \frac{8\pi hc}{\lambda^5}\frac{1}{e^{hc/\lambda KT} - 1}\,. \qquad (6)\end{aligned}$$

Photo-electric Effect



$$
\begin{aligned}
\text{Light Energy} - \text{WorkFunction} &= \text{Electron Energy} \\
h\nu - \Phi &= \frac{1}{2}mv^2 \\
h\nu - h\nu_0 &= eV \qquad (7)
\end{aligned}
$$

Compton Scattering:



Summary

- **Question**: What is Light?
- **Ans:** Just consider as Ray/something flowing. Just focus on its direction (Ray Optics/Geometrical Optics)
- **Ans:** It is a Wave. Just like Sound, **some quantity (??)** is fluctuating with time ans space (Physical Optics)
- **Ans:** Light is fluctuating Electric & Magnetic field – An Electro-magnetic Wave (Classical Electrodynamics)
- **Ans:** Light is basically billions of photon particles with cpeed c (Quantum Mechanics, Special Theory of Relativity)
- **Last Question**: What is Light? Rays?, Wave? Or Particles?
- **Ans:** ....No Answer....:)...

Niels Bohr
(1885-1962)

Prevous Courses : De Broglie hypothesis, Wave-particle duality, Group and phase velocities, Heisenberg's uncertainty etc.

↓

Particle in a Box (Quantum Mechanics)

↓

Latter Courses : Few more application of Schrodenger's Equation,...... Hydrogen Atom Problem (Origin of Atomic spectra) etc.

Photon

Max Planck
(1858-1947)

Light/ E.M. Wave

Experimental Facts

- Black Body Radiation
- Photo electric Effect
- Compton Scattering

Particle quantities

Wave quantities

Energy $E = \hbar\omega$ Angular Frequency

Momentum $p = \hbar k$ Propagation constant

Particle

Louis de Broglie
(1892-1987)

Matter Wave

de-Broglie wave equation

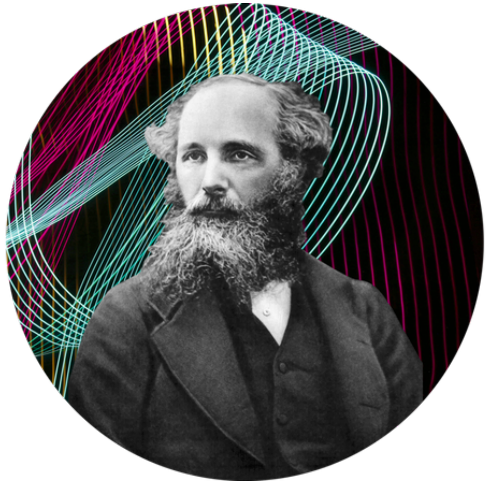
$$\lambda = \frac{h}{p}$$

Particle

Louis de Broglie
(1892-1987)

Matter Wave

- Newton's Equation
- Euler-Lagrangian Equation
- Hamiltonian Equation



Wave equation Light wave:

$$\frac{\partial^2 \psi}{\partial x^2} = \frac{1}{c^2}\frac{\partial^2 \psi}{\partial t^2}$$

Solution:

$$\begin{aligned}\psi(x,t) &= Ae^{i(kx-\omega t)} \\ &= Ae^{i2\pi(\frac{x}{\lambda}-\nu t)} ,\end{aligned}$$

where $c = \frac{\omega}{k} = \nu\lambda$.

Electro Magnetic Wave

Erwin Schrödinger
(1887-1961)

Wave equation of particle/Matter wave:

$$\frac{-\hbar^2}{2m}\frac{\partial^2 \psi}{\partial x^2} + V(x)\psi = i\hbar\frac{\partial \psi}{\partial t}$$

Solution:

$$\psi(x,t) = Ae^{i(px-Et)/\hbar}$$

Matter Wave

Wave function $\psi \approx e^{j(\omega t - k_x x)}$

$$\frac{\partial}{\partial t}\psi = j\omega\psi \quad \Rightarrow \quad E\psi = \hbar\omega\psi = -j\hbar\frac{\partial}{\partial t}\psi$$

$$\frac{\partial}{\partial x}\psi = -jk_x\psi \quad \Rightarrow \quad p_x\psi = \hbar k_x\psi = j\hbar\frac{\partial}{\partial x}\psi$$

Particle $E = \frac{p^2}{2m}$ (free-particle)

$$\boxed{-j\hbar\frac{\partial}{\partial t}\psi = -\frac{\hbar^2}{2m}\frac{\partial^2\psi}{\partial x^2}}$$

Matter Wave associated with free particle

Schrodinger equation with potential term

$$\boxed{-j\hbar\frac{\partial}{\partial t}\psi = -\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2} + V(x)\psi}$$

- Time-harmonic solutions to Schrodinger equation are of the form: $\boxed{\Psi(x,t) = e^{-iEt/\hbar}\psi(x)}$
- Ψ(x,t) is a measurable quantity and represents the probability distribution of finding the particle.

Time-Dependent Schrodinger Wave Equation

$$i\hbar\frac{\partial}{\partial t}\Psi(x,t) = -\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\Psi(x,t) + V(x)\Psi(x,t)$$

Total E term

K.E. term

P.E. term

$$\Psi(x,t) = e^{-iEt/\hbar}\psi(x)$$

Time-Independent Schrodinger Wave Equation

$$E\psi(x) = -\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\psi(x) + V(x)\psi(x)$$

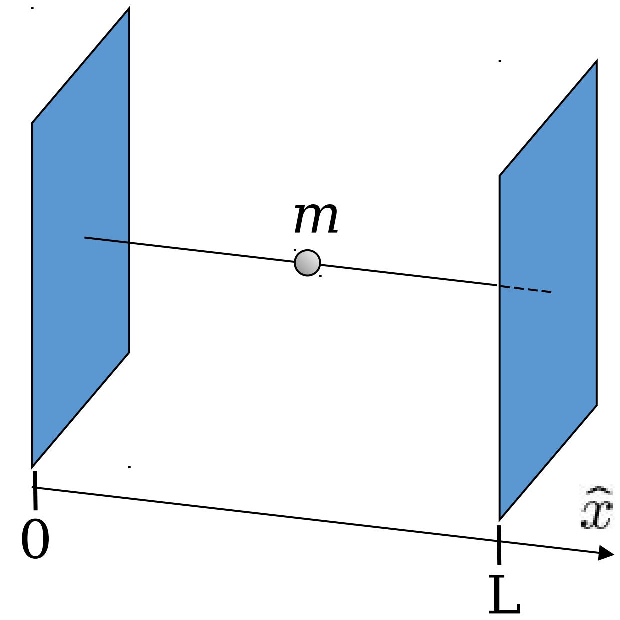
A point mass m constrained to move on an infinitely-thin, frictionless wire which is strung tightly between two impenetrable walls a distance L apart

for $(x \leq 0, x \geq L)$

$$V(x) = \infty$$

$$E\psi = -\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\psi + (\infty)\psi$$

$\Rightarrow$ $\psi = 0$



for $(0 < x < L)$

$$V(x) = 0$$

$$E\psi = -\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\psi$$

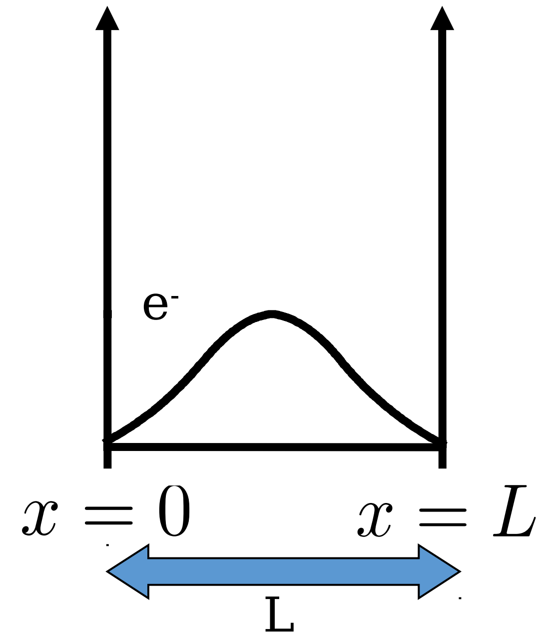
$\Rightarrow$ $\psi(0) = \psi(L) = 0$

As wave function must be CONTINUOUS

for $(0 < x < L): \; V(x) = 0$

$$E_n \psi_n = -\frac{\hbar^2}{2m} \frac{\partial^2 \psi_n}{\partial x^2}$$

WE WILL HAVE MULTIPLE SOLUTIONS, SO WE INTRODUCE LABEL *n*



REWRITE AS:

$$\frac{\partial^2 \psi_n}{\partial x^2} + k_n^2 \psi_n = 0 \qquad \text{WHERE} \qquad k_n^2 = \frac{2mE_n}{\hbar^2}$$

GENERAL SOLUTION:

$$\psi_n(x) = A \sin k_n x + B \cos k_n x \quad \text{OR} \quad \psi_n = C_1 e^{jk_n x} + C_2 e^{-jk_n x}$$

USE BOUNDARY CONDITIONS TO DETERMINE COEFFICIENTS A and B

$$\psi(0) = 0 \quad \Rightarrow \quad B = 0$$

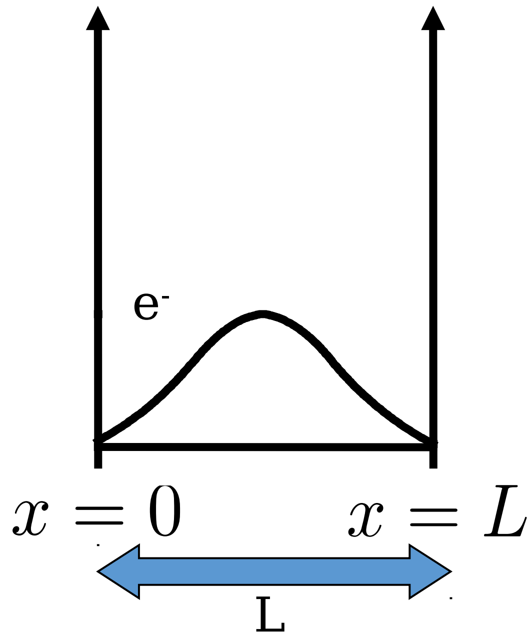
$$\psi(L) = 0 \quad \Rightarrow \quad k_n L = n\pi$$

$$\Downarrow$$

$$k_n^2 = \frac{2mE_n}{\hbar^2}$$

$$\Downarrow$$

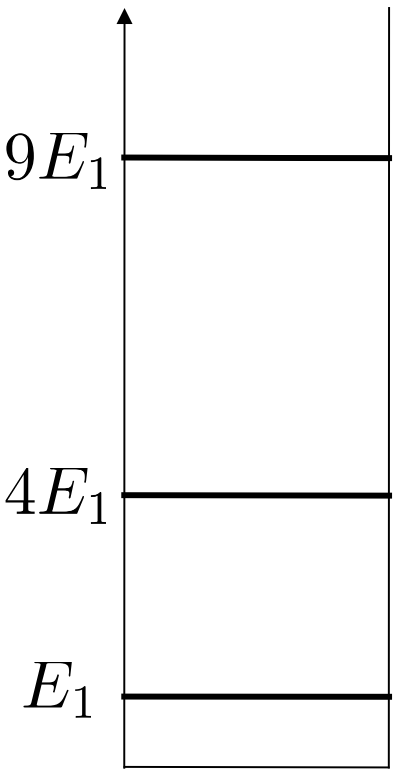
$$E_n = n^2 E_1 \quad \Leftarrow \quad E_1 = \frac{\hbar^2 k_1^2}{2m} = \frac{\hbar^2 \pi^2}{2mL^2}$$



NORMALIZE THE INTEGRAL OF PROBABILITY TO 1

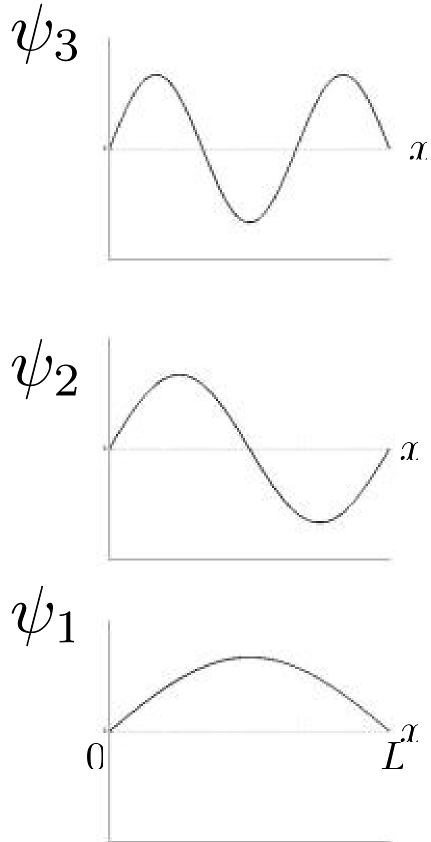
$$\psi(x) = \sqrt{\frac{2}{L}} \sin \frac{n\pi x}{L}$$

EIGEN ENERGIES for 1-D BOX



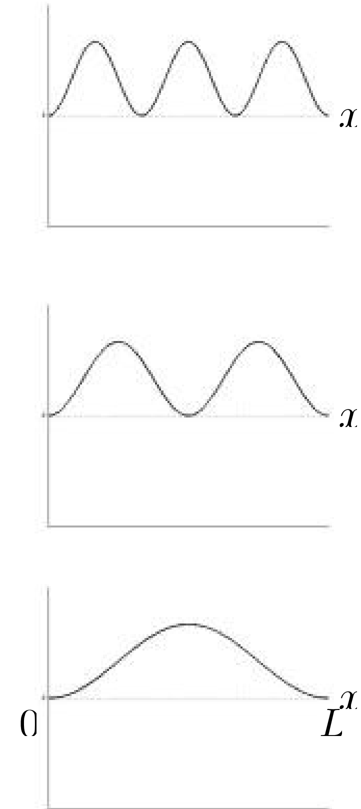
$$E_n = n^2 E_1$$

EIGEN STATES For 1-D BOX



$$\psi(x) = \sqrt{\frac{2}{L}} \sin \frac{n\pi x}{L}$$

PROBABILITY DENSITIES



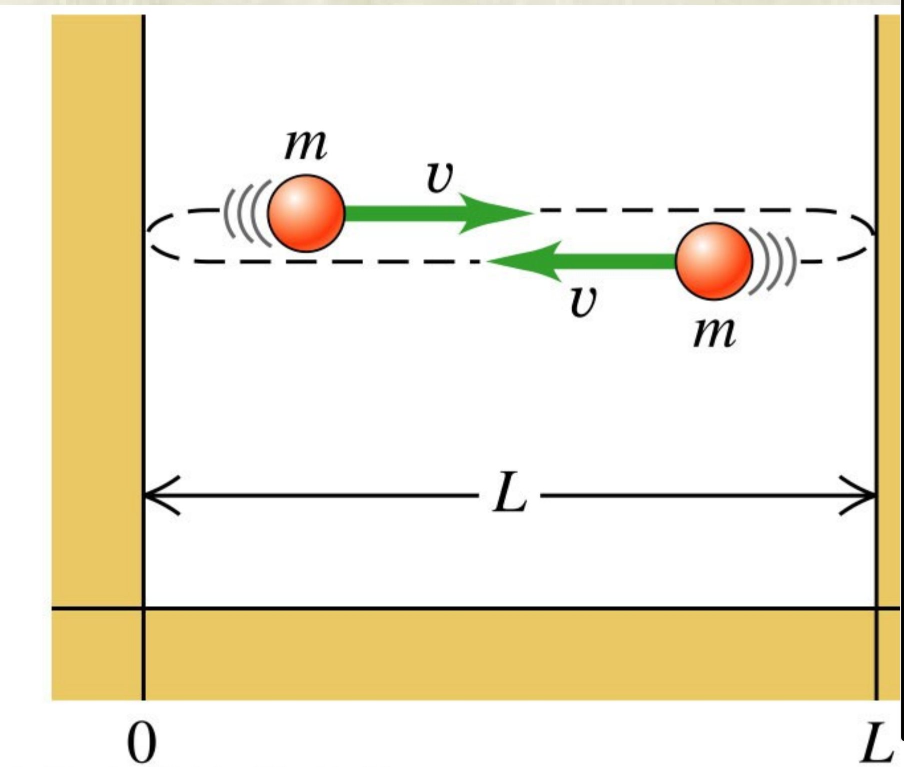
$$P(x) = |\psi(x)|^2 \, dx = \frac{2}{L} \sin^2 \frac{n\pi x}{L} dx$$

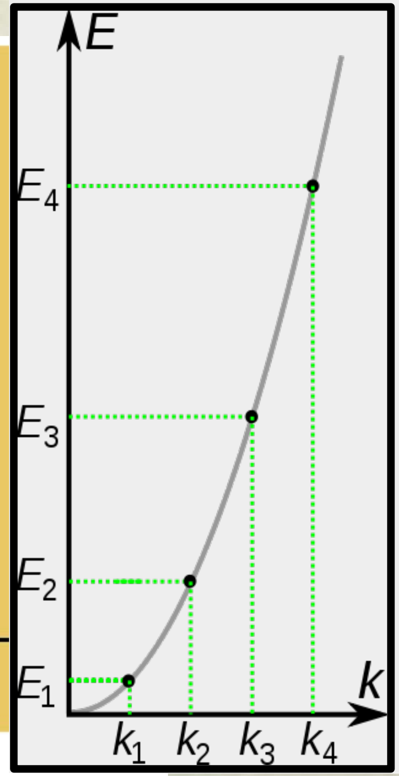
Classical View :

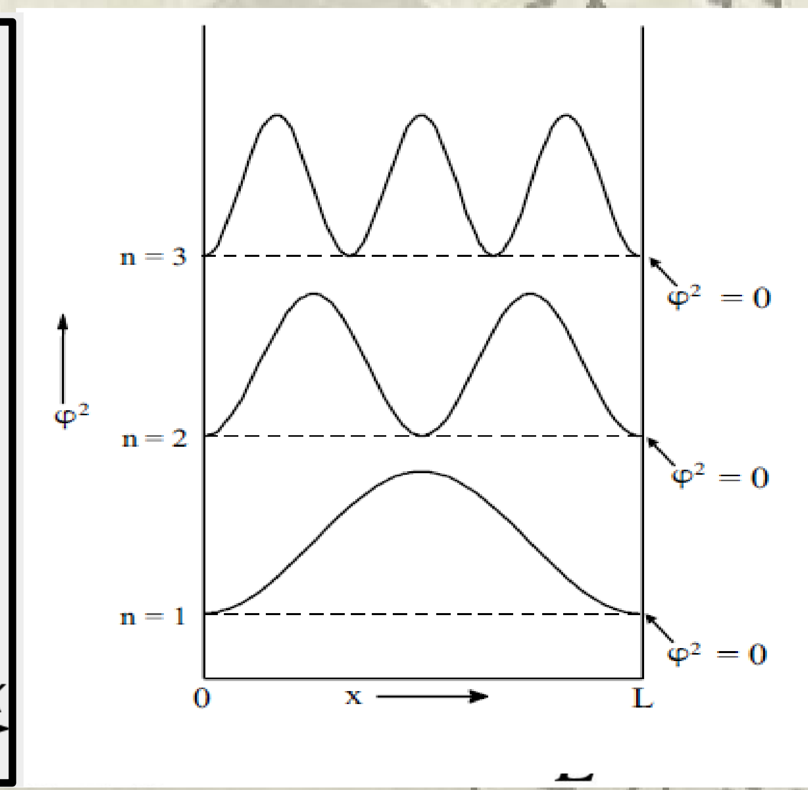
Quantum View :

- **Definite Existence in space**

- **Probabilistic Existence in space**







$$E = \frac{p^2}{2m}$$

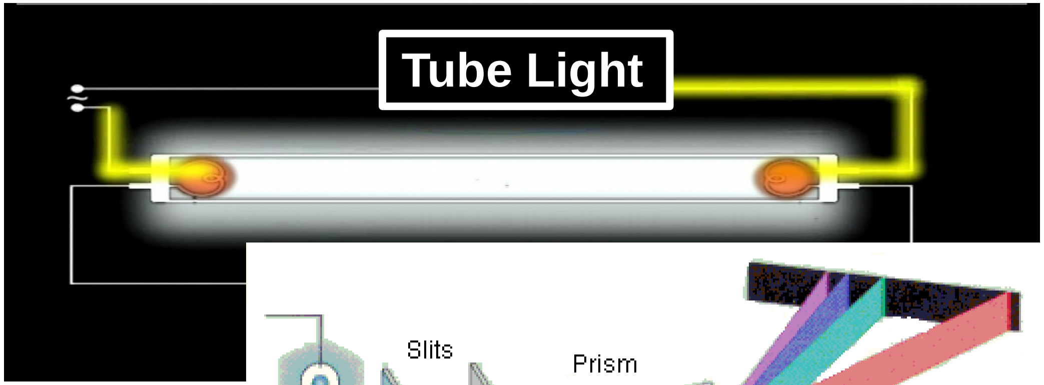
$$E_n = n^2 E_1$$

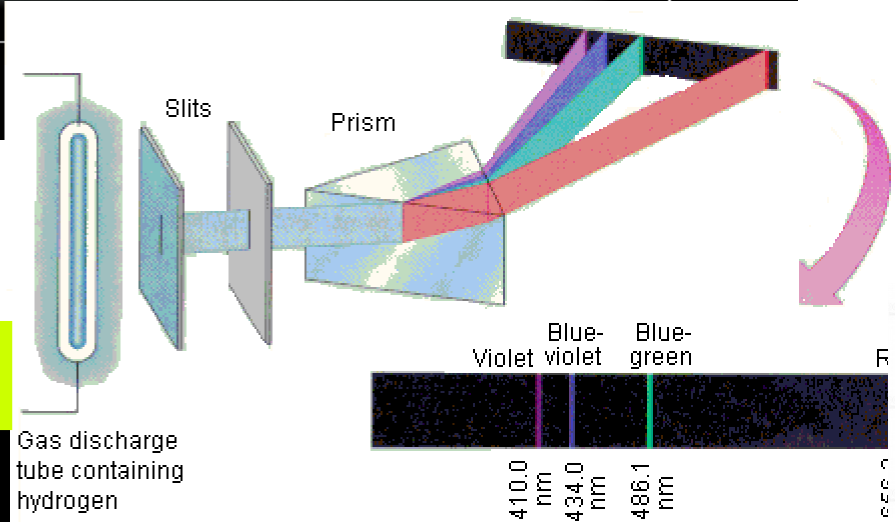
$$E_1 = \frac{\hbar^2 k_1^2}{2m} = \frac{\hbar^2 \pi^2}{2mL^2}$$

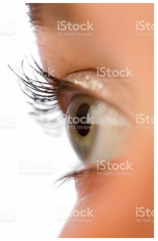
- **Energy can varry continously**

- **Available Energies are quantized**

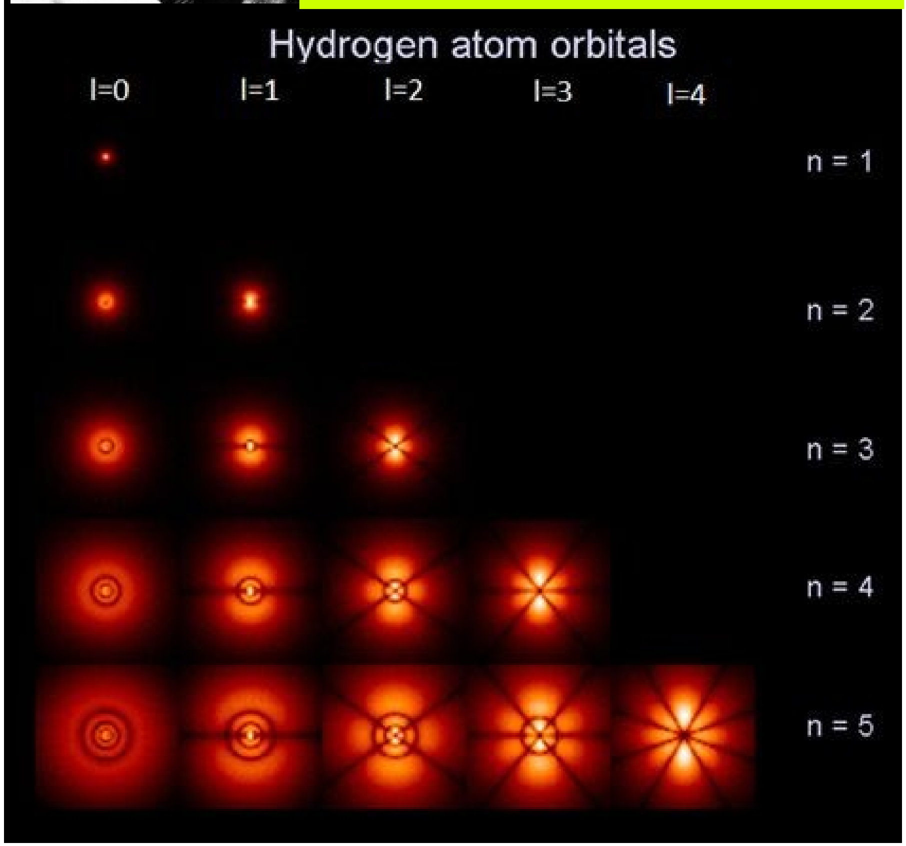
Aim is to understand the origin of Atomic Spectra



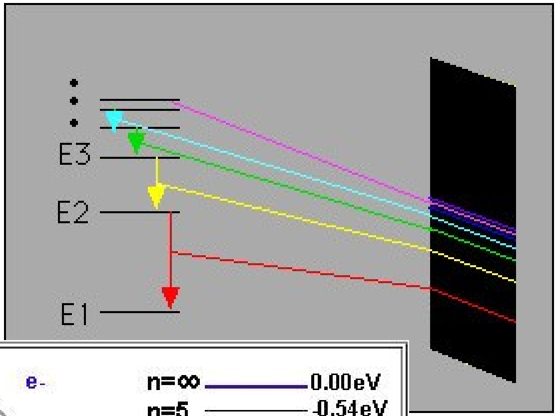


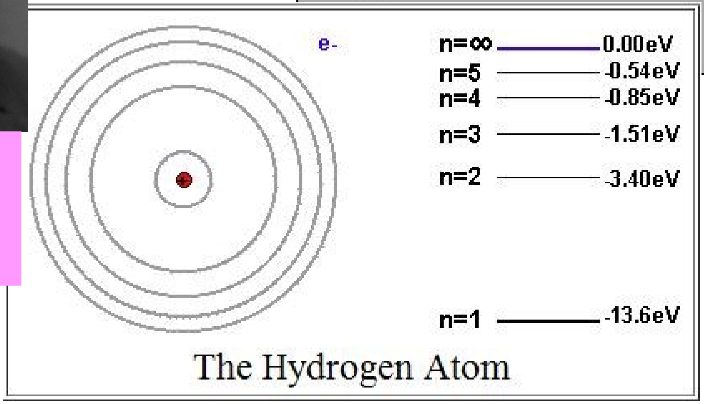


Picture from Schrodinger's Equation



Bohr's atomic model





Tutorial Part

Question: An electron is in 1D box of 1nm length. What is the probability of locating the electron between x=0 and x=0.2nm in its lowest energy state?

Solution:

$$P(x_1, x_2) = \int_{x_1}^{x_2} |\psi(x)|^2 \, dx$$

$$\int_{x=0\ \text{nm}}^{0.2\ \text{nm}} |\psi_1(x)|^2 \, dx = \overbrace{\frac{2}{1.0\ \text{nm}} \int_{0\ \text{nm}}^{0.2\ \text{nm}} \sin^2\left(\frac{\pi x}{1.0\ \text{nm}}\right) dx}^{n=1, a=1\ \text{nm}}$$

$$\int \sin^2\left(\frac{\pi}{a}x\right) dx = \frac{x}{2} - \frac{\sin(2\pi x/a)}{4\pi/a}\Bigg)$$

$$= \frac{2}{1.0\ \text{nm}} \left(\frac{0.2\ \text{nm}}{2} - \frac{\sin(2\pi \times (0.2\ \text{nm})/(1.0\ \text{nm}))}{4\pi/(1.0\ \text{nm})}\right) \approx 0.05$$

Example: What are the most likely locations of a particle in a box of length L in the state n=3

$$\psi_3 = \sqrt{\frac{2}{L}}\sin\left(\frac{3\pi x}{L}\right)$$

$$P(x) \propto \psi_3 \psi_3 \propto \sin^2\left(\frac{3\pi x}{L}\right)$$

The maxima and minima in P(x) corresponds to $\frac{dP(x)}{dx} = 0$

$$\frac{dP(x)}{dx} \propto \sin\left(\frac{3\pi x}{L}\right)\cos\left(\frac{3\pi x}{L}\right) \propto \sin\left(\frac{6\pi x}{L}\right)$$

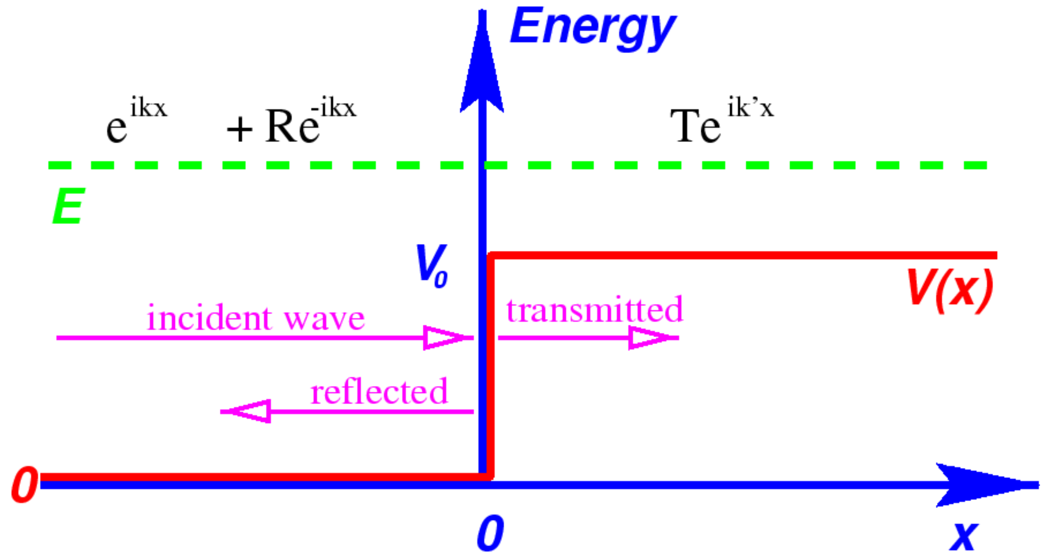
$$\sin\theta = 0 \text{ when } \theta = \left(\frac{6\pi x}{L}\right) = n'\pi,\ n = 0,1,2.....$$

which corresponds to $x = \frac{n' L}{6},\ n' < 6.$

$n' = 0, 2, 4,$ and 6 corresponds to minima in

$n' = 1, 3,$ and 5 to maxima

Step potential:



Potential :

$$V(x<0) = 0\ ,$$
$$V(x\geq 0) = V_0\ , \tag{21}$$

Schrodenger's Equations :

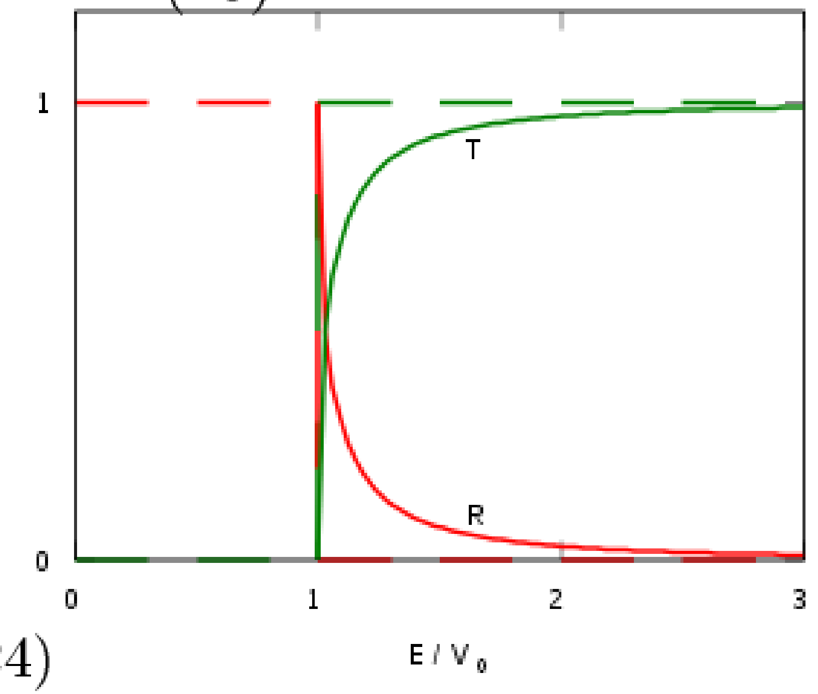
$$\frac{\partial^2\psi_1}{\partial x^2} + k_1^2\psi_1 = 0\ ,\ \text{with}\ k_1^2 = \frac{2mE}{\hbar^2}$$
$$\frac{\partial^2\psi_1}{\partial x^2} + k_2^2\psi_1 = 0\ ,\ \text{with}\ k_2^2 = \frac{2m(E-V_0)}{\hbar^2} \tag{22}$$

E<V_0

Guess Solutions:

E<V_0

$$\begin{aligned}\psi_1 &= Ae^{ik_1x} + Be^{-ik_1x} \\ \psi_2 &= Ce^{ik_2x} + {\color{red}De^{-ik_2x}}\end{aligned} \tag{23}$$



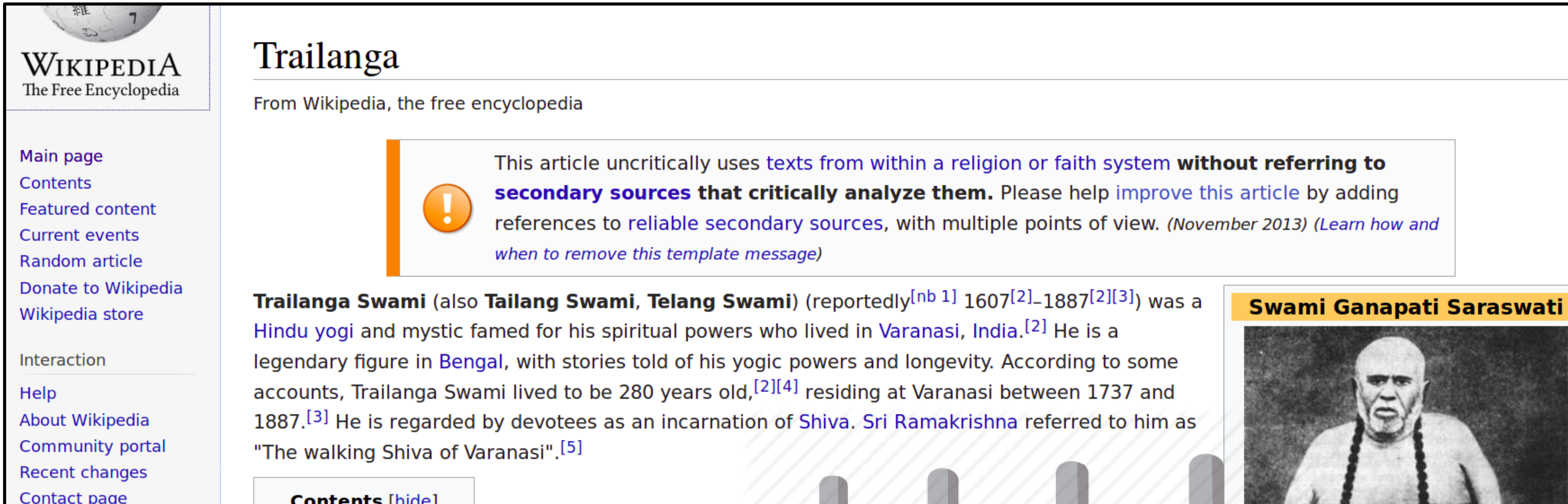
Boundary Conditions:

$$\begin{aligned}\psi_1(x=0) = \psi_2(x=0) &\Rightarrow A + B = C \\ \left(\frac{\partial\psi_1}{\partial x}\right)_{x=0} = \left(\frac{\partial\psi_2}{\partial x}\right)_{x=0} &\Rightarrow A - B = \frac{k_2}{k_1}C\end{aligned} \tag{24}$$

So the transmitted and reflection coefficients are

$$\begin{aligned}T &= \frac{\hbar k_2}{\hbar k_1}\left|\frac{C}{A}\right|^2 = \frac{4k_1k_2}{(k_1+k_2)^2} \\ R &= \frac{\hbar k_1}{\hbar k_1}\left|\frac{B}{A}\right|^2 = \frac{(k_1-k_2)^2}{(k_1+k_2)^2}\ .\end{aligned} \tag{25}$$

Tunneling Effect:



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Trailanga

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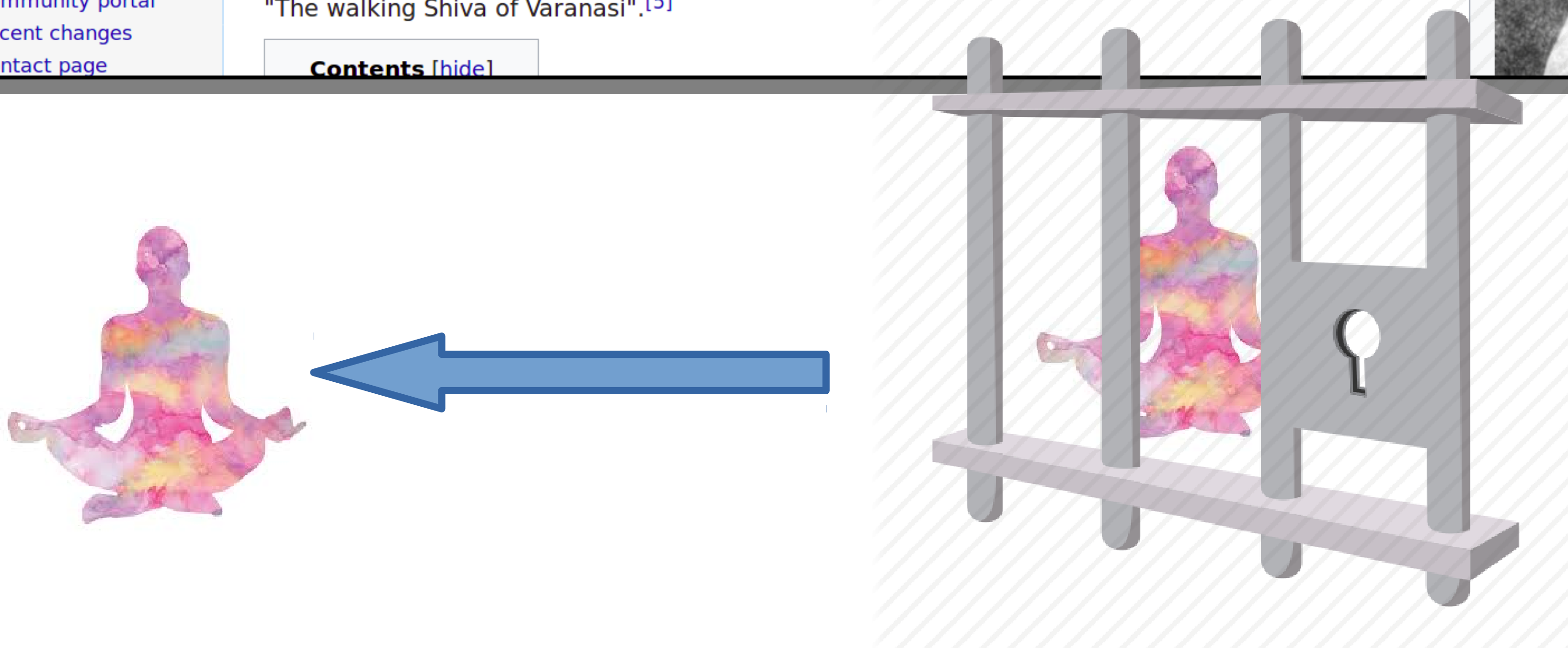
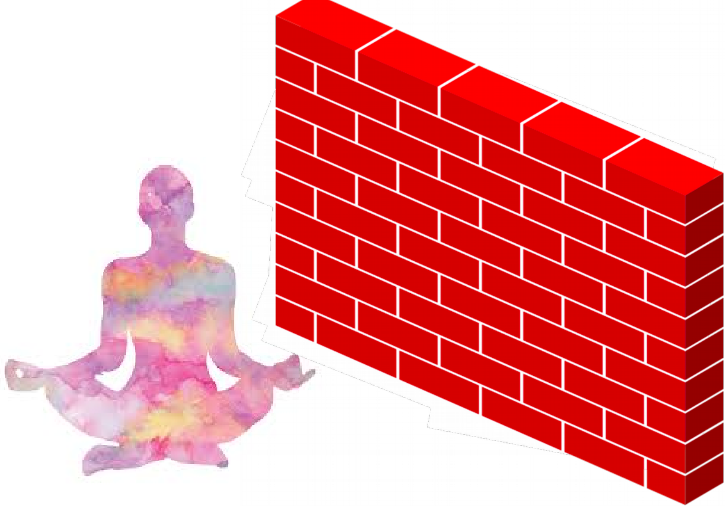
This article uncritically uses texts from within a religion or faith system **without referring to secondary sources that critically analyze them.** Please help improve this article by adding references to reliable secondary sources, with multiple points of view. *(November 2013) (Learn how and when to remove this template message)*

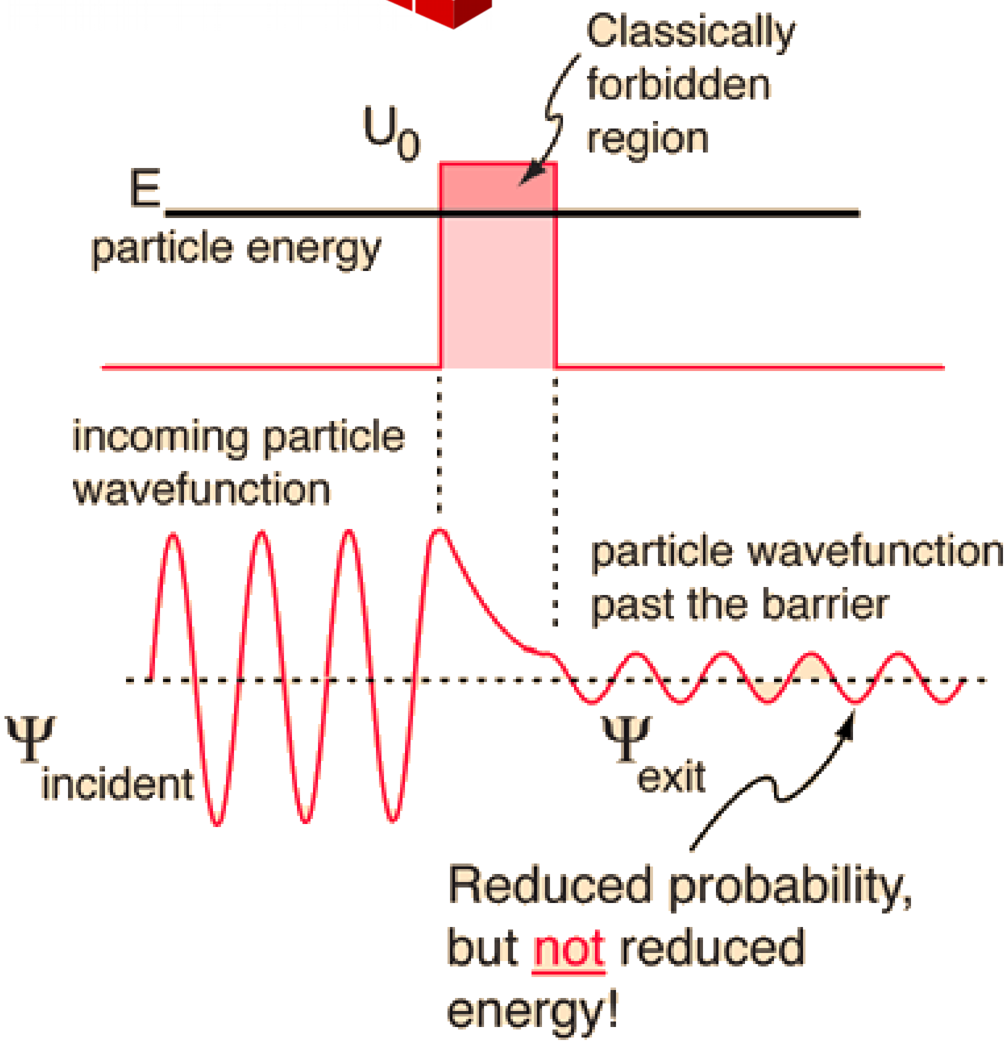
Trailanga Swami (also **Tailang Swami**, **Telang Swami**) (reportedly[nb 1] 1607[2]–1887[2][3]) was a Hindu yogi and mystic famed for his spiritual powers who lived in Varanasi, India.[2] He is a legendary figure in Bengal, with stories told of his yogic powers and longevity. According to some accounts, Trailanga Swami lived to be 280 years old,[2][4] residing at Varanasi between 1737 and 1887.[3] He is regarded by devotees as an incarnation of Shiva. Sri Ramakrishna referred to him as "The walking Shiva of Varanasi".[5]

Contents [hide]

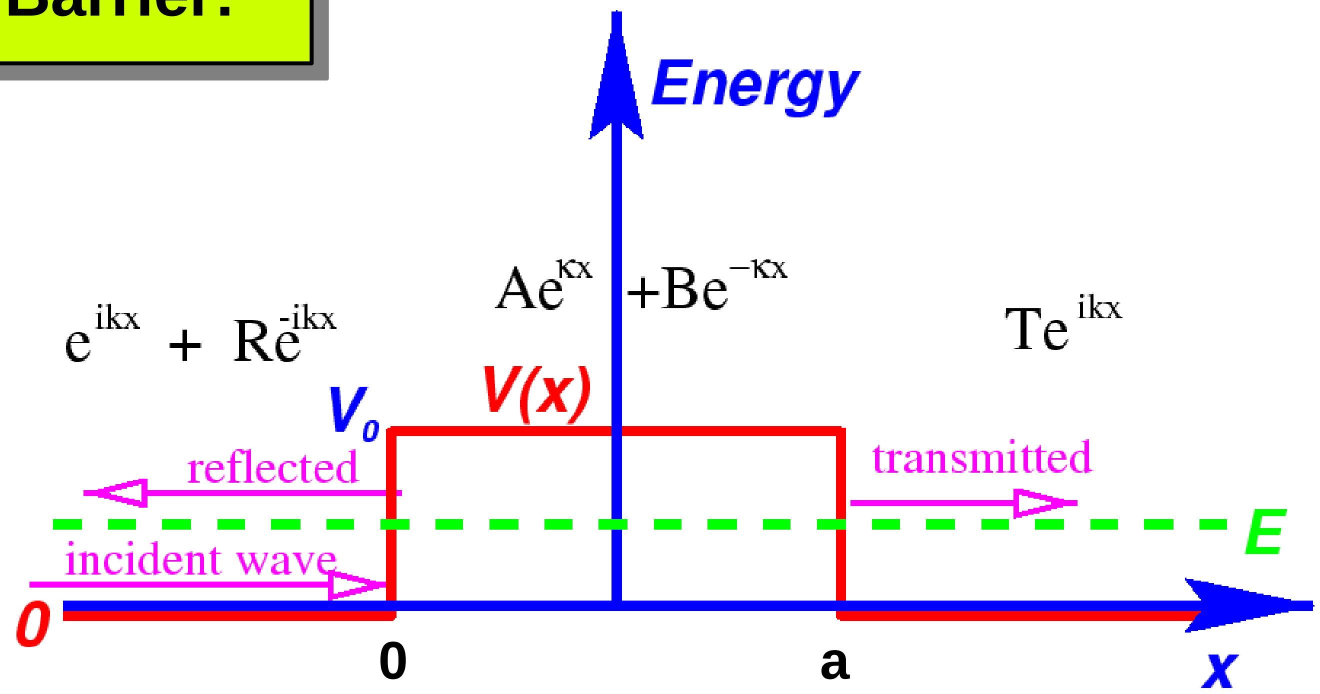
Swami Ganapati Saraswati



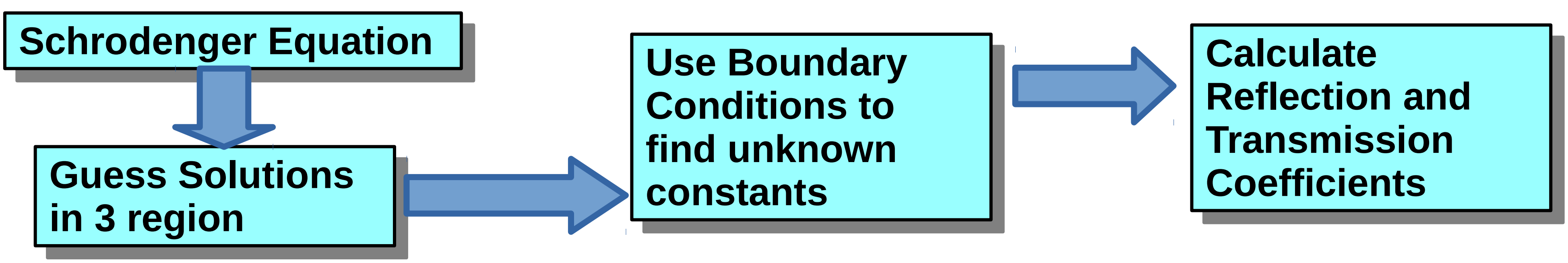



Classically
forbidden
region
U0
E
particle energy
incoming particle
wavefunction
particle wavefunction
past the barrier
Ψ incident
Ψ exit
Reduced probability,
but not reduced
energy!

Potential Barrier:



$$V(x) = \begin{cases} 0 & \text{if } x < 0 \\ V_0 & \text{if } 0 < x < a \\ 0 & \text{if } a < x \end{cases}$$

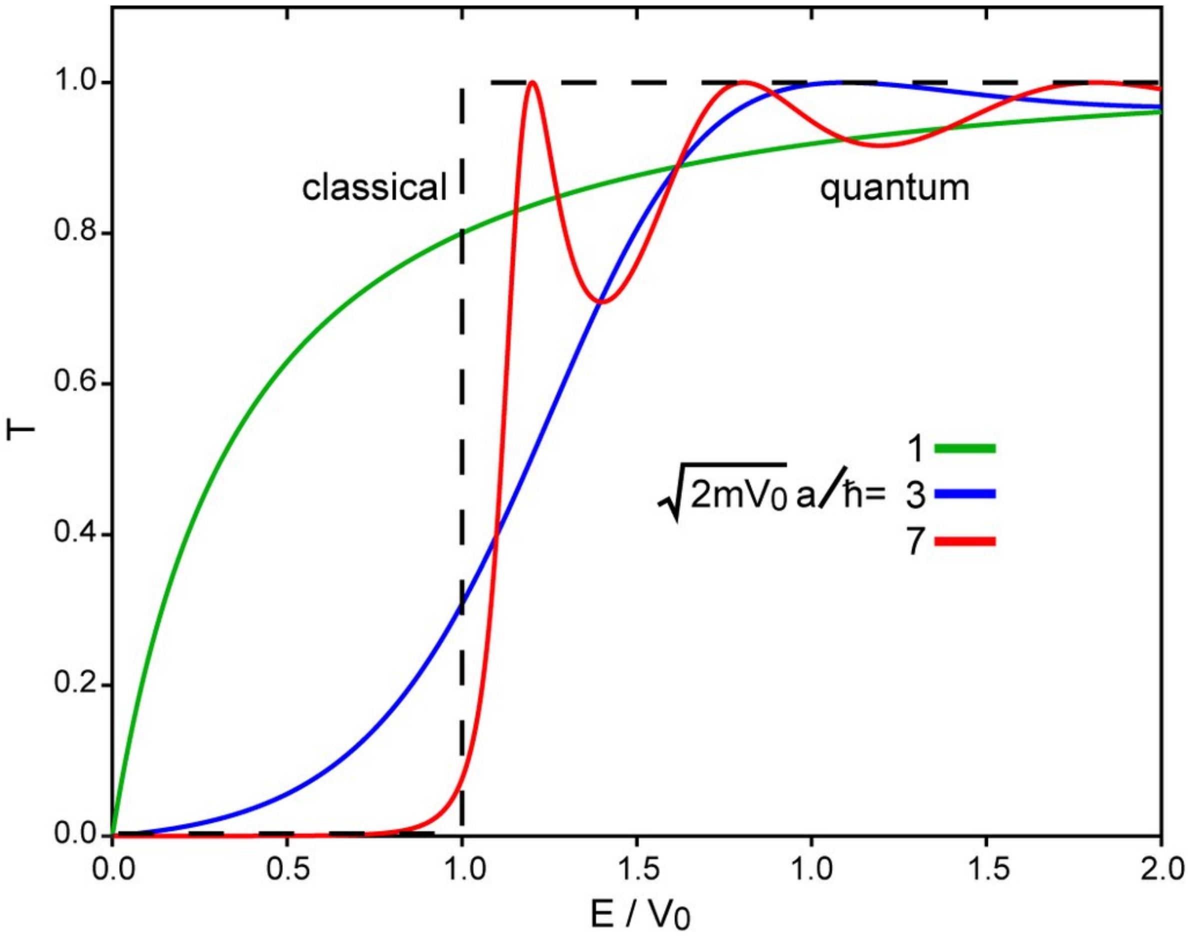


Tunneling Effect:

$E < V_0$ [edit]

The surprising result is that for energies less than the barrier height, $E < V_0$ there is a non-zero probability

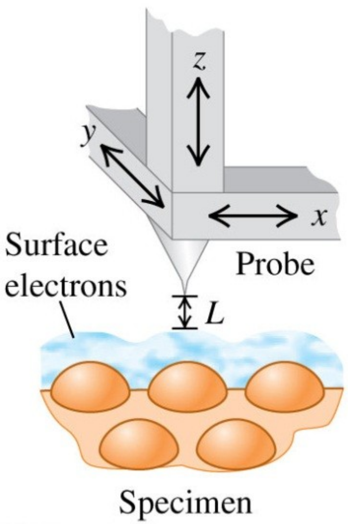
$$T = |t|^2 = \frac{1}{1 + \frac{V_0^2 \sinh^2(k_1 a)}{4E(V_0 - E)}}$$



Applications of tunneling

- A scanning tunneling microscope measures the atomic topography of a surface. It does this by measuring the current of electrons tunneling between the surface and a probe with a sharp tip. As the tip nears an atom, the barrier gets thinner, so the current indicates how close the atom is to the tip (the height of the surface)
- An alpha particle inside an unstable nucleus can only escape via tunneling. The reverse happens in fusion, such as what goes on in the Sun.

(a)



(b)