

# Physics 102 - February 19, 2014

## Maxwell's Equations 1873

Wave equations  
Refraction  
Diffraction  
Interference

Light is a Wave



James Clerk Maxwell  
1831-1879 (Edinburgh)

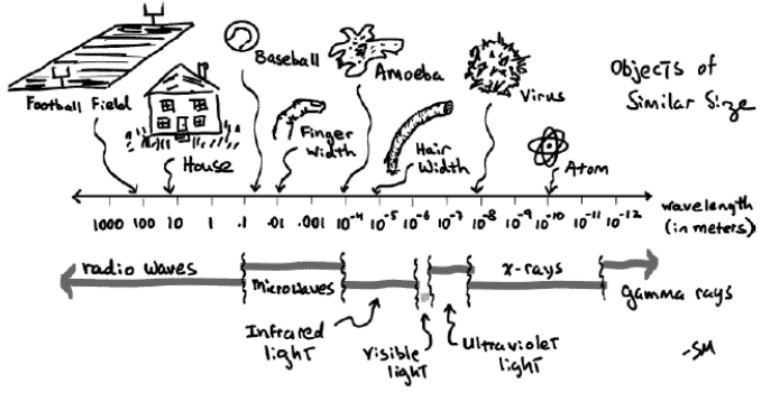
$$\oint_s \vec{E} \cdot d\vec{a} = \frac{Q_{encl}}{\epsilon_0}$$

$$\oint_s \vec{B} \cdot d\vec{a} = 0$$

$$\int_c \vec{E} \cdot d\vec{l} = - \frac{d \int_s \vec{B} \cdot d\vec{a}}{dt}$$

$$\int_c \vec{B} \cdot d\vec{l} = \mu_0 I_{encl} + \mu_0 \epsilon_0 \frac{d \int_s \vec{E} \cdot d\vec{a}}{dt}$$

### The variety of electromagnetic waves



Objects of similar size  
electric field  
magnetic field

## Refraction of light

Speed of light in vacuum  $\equiv c - 3 \times 10^8 \text{ m/s}$

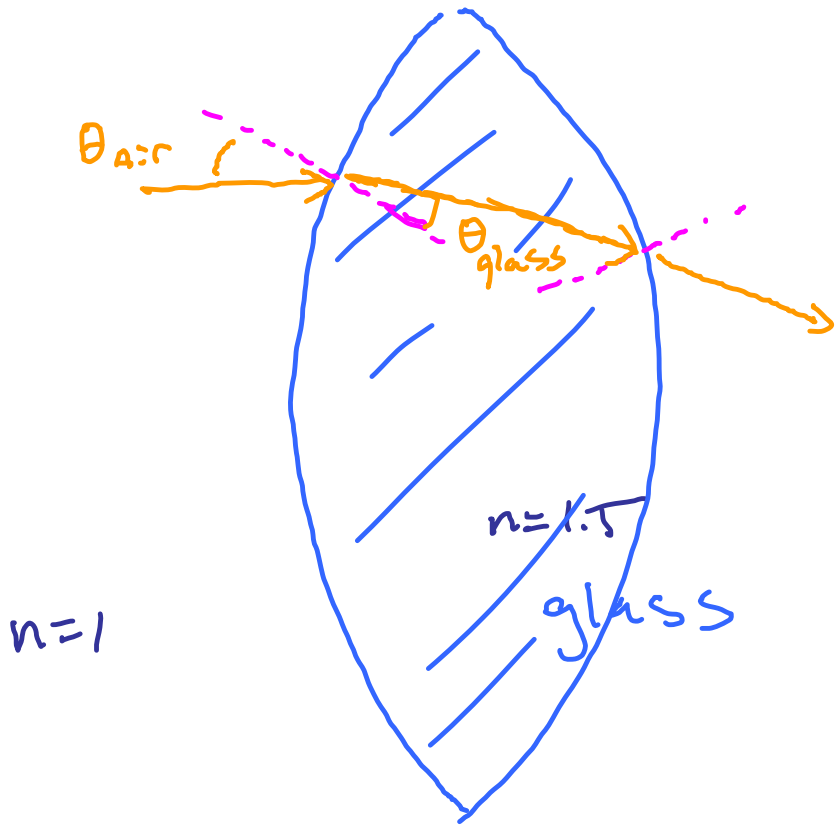
Speed of light in a medium  $\equiv v < c$

index of refraction  $n \geq 1$        $n = \frac{c}{v}$

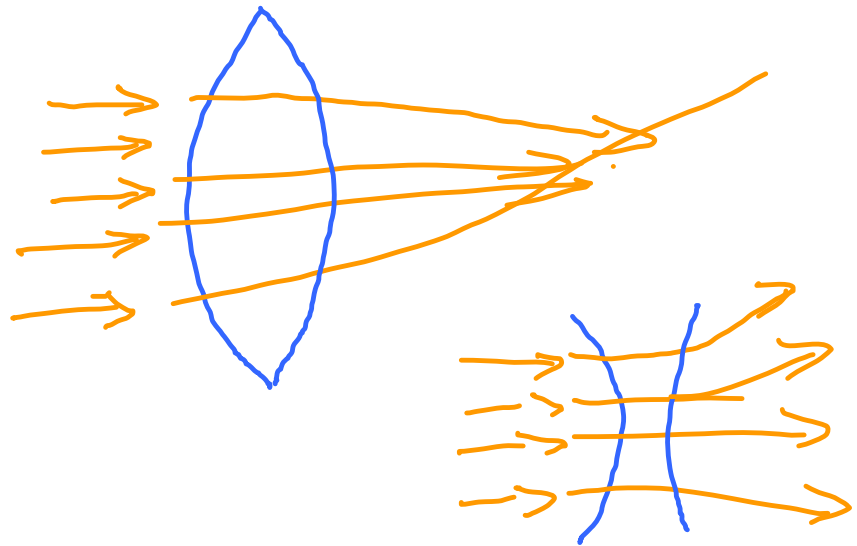
Air has  $n \sim 1$

glass has  $n \sim 1.5$

water has  $n \sim 1.33$



$$n_{air} \sin \theta_{air} = n_{glass} \sin \theta_{glass}$$



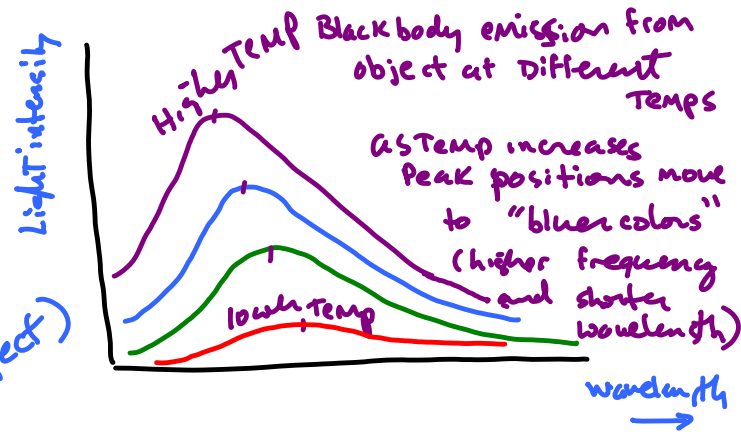


Max Planck  
(1858-1947)

German national

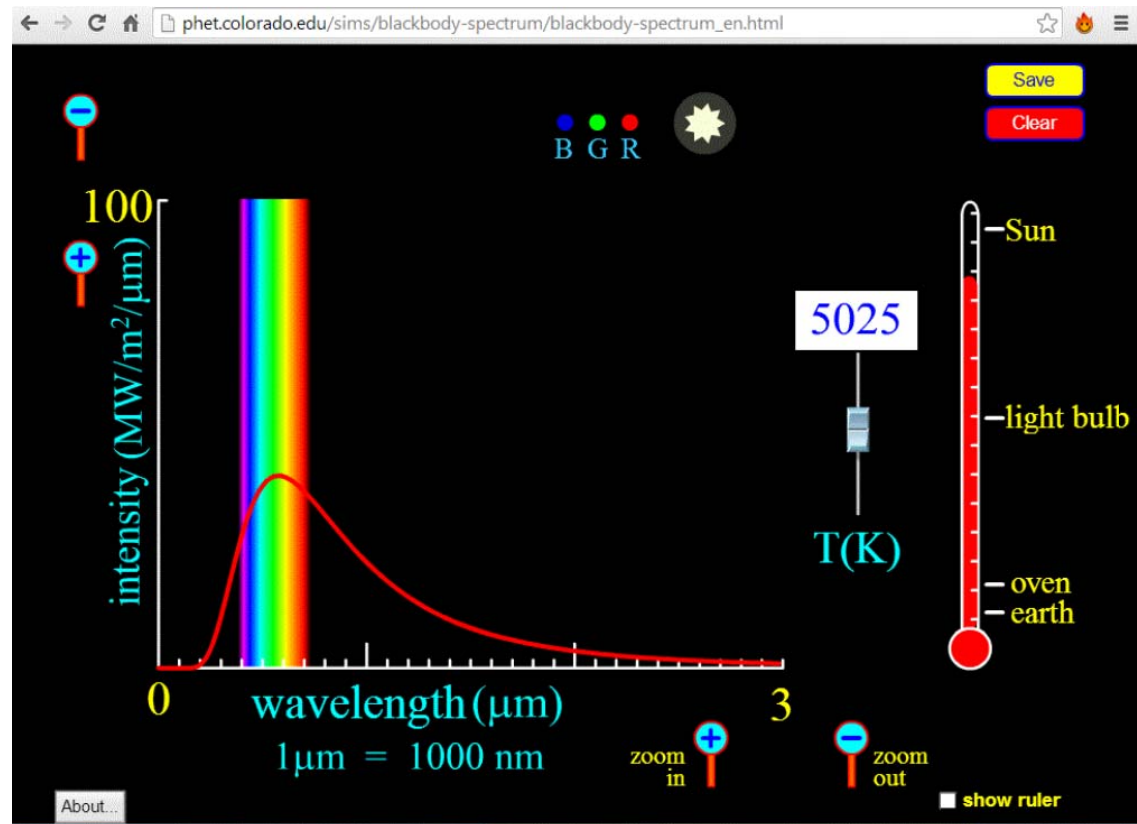
Awarded 1918 Nobel Prize in physics  
for analysis of blackbody radiation  
which contributed to rise of  
quantum Mechanics

<http://www-history.mcs.st->



Fantastic java applet for Blackbody radiation

[http://phet.colorado.edu/sims/blackbody-spectrum/blackbody-spectrum\\_en.html](http://phet.colorado.edu/sims/blackbody-spectrum/blackbody-spectrum_en.html)

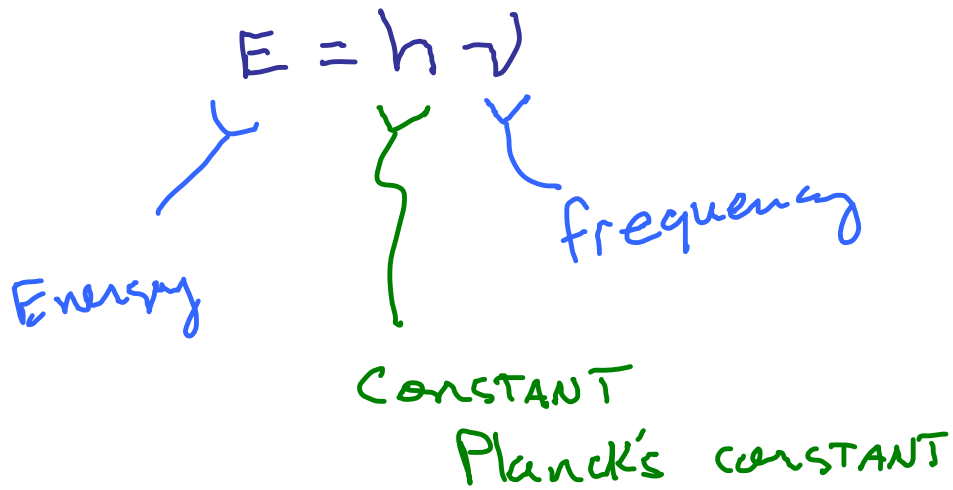


$$E = h \nu$$

Energy

frequency

CONSTANT  
Planck's constant



Energy is quantized

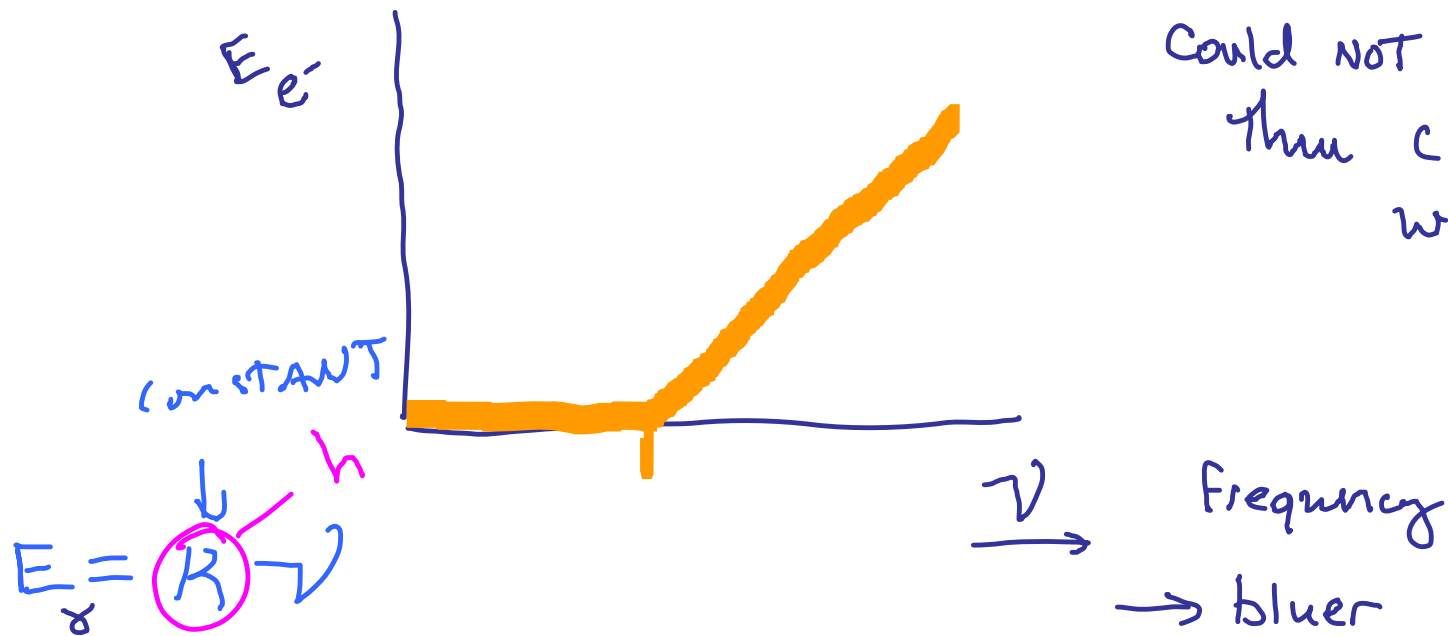
light comes as discrete particles  
"photons"

Photoelectric effect



Fantastic java applet for the photoelectric effect  
<http://phet.colorado.edu/en/simulation/photoelectric>

The screenshot shows the PhET Photoelectric Effect simulation interface. The main window displays a vacuum tube setup with two metal plates. A light source on the left emits a purple beam of light towards the left plate. A control panel above the tube shows an 'Intensity' slider set to 19% and a wavelength selector set to 400 nm. The spectrum below the slider ranges from UV to IR. The circuit is connected to a battery labeled '0.00 V' and a current meter showing 'Current: 0.027'. Several blue dots representing electrons are shown moving from the left plate to the right plate. The right sidebar contains a 'Target' dropdown menu set to 'Sodium', a checkbox for 'Show only highest energy electrons', and a 'Graphs' section with three unchecked options: 'Current vs battery voltage', 'Current vs light intensity', and 'Electron energy vs light frequency'. The PhET logo is visible at the top of the sidebar. At the bottom of the window, there are pause and play buttons.





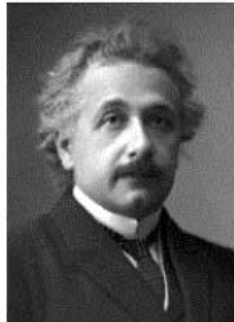


The Nobel Prize in Physics 1921

Albert Einstein

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# The Nobel Prize in Physics 1921

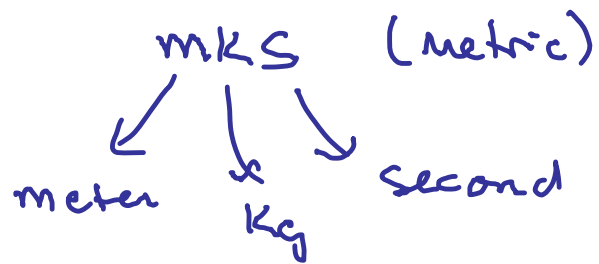


Albert Einstein

The Nobel Prize in Physics 1921 was awarded to Albert Einstein *"for his services to Theoretical Physics, and especially for his discovery of the law of the photoelectric effect"*.

Slight detour →

units of energy and mass



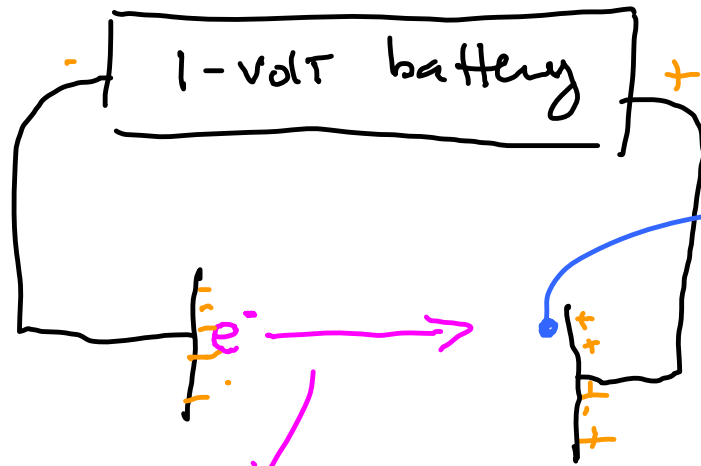
→ unit of energy Joule

Power is measured of energy/time

100 Watt light bulb

emits 100 Joules/second of energy

# Energy of light or other particles



force Accelerates electron

at this point  
electron has an  
energy of  
1 electron-volt  
1 eV  
 $= 1.6 \times 10^{-19}$  Joules

eV	electron volt
keV	Thousands of eV
MeV	Millions of eV
GeV	billions of eV
TeV	Thousand of billions of eV

Large hadron  
collider  
 $E \sim 14 \text{ TeV}$

$$E = mc^2$$

mass of particles in  $\text{eV}/c^2$

mass of electron  $0.511 \text{ MeV}/c^2 \rightarrow 0.511 \text{ MeV}$

mass of proton  $\sim 1 \text{ GeV}/c^2 \rightarrow 1 \text{ GeV}$

mid-1920's

Louis de Broglie

hypothesized particles might have wavelike properties

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

$$\begin{aligned} E &= h\nu \\ \nu &= \frac{c}{\lambda} \\ c &= \lambda\nu \end{aligned}$$

$$E = \frac{hc}{\lambda} \rightarrow \frac{h}{\lambda} = \frac{E}{c}$$

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

$$E = \sqrt{p^2 c^2 + m^2 c^4}$$

$$m=0 \rightarrow E = pc \quad p = \frac{E}{c}$$

photon

