Physics 104

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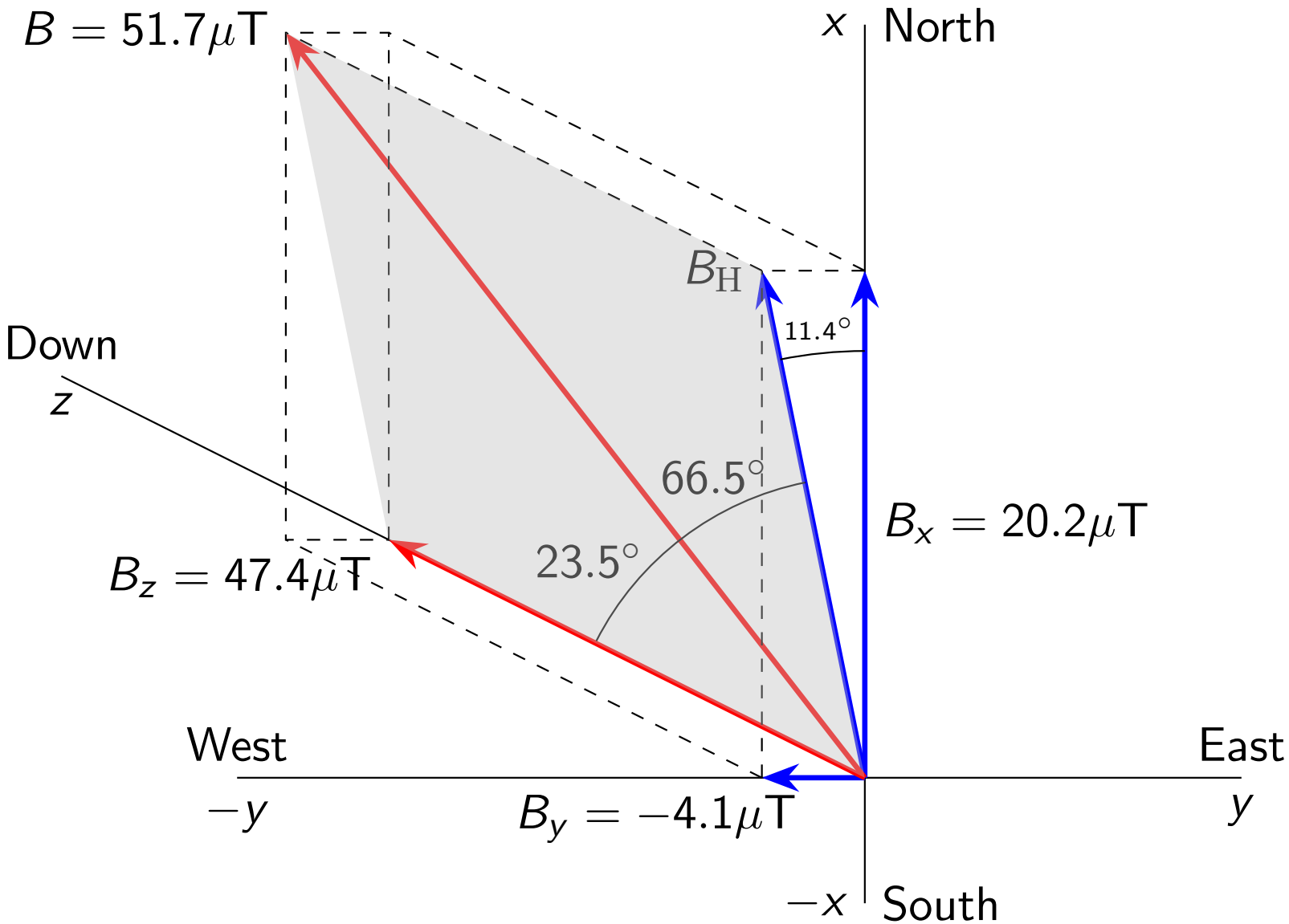
Earth's magnetic field in Annville, PA

B_x	20.2 μT	x is North
B_y	-4.1 μT	y is East
B_z	47.4 μT	z is Down
Horizontal Intensity	20.6 μT	
Total Field	51.7 μT	
Inclination (+ D , − U)	66.5°	
Declination (+ E , − W)	-11.4°	

Data source:

`https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml#igrfwmm`

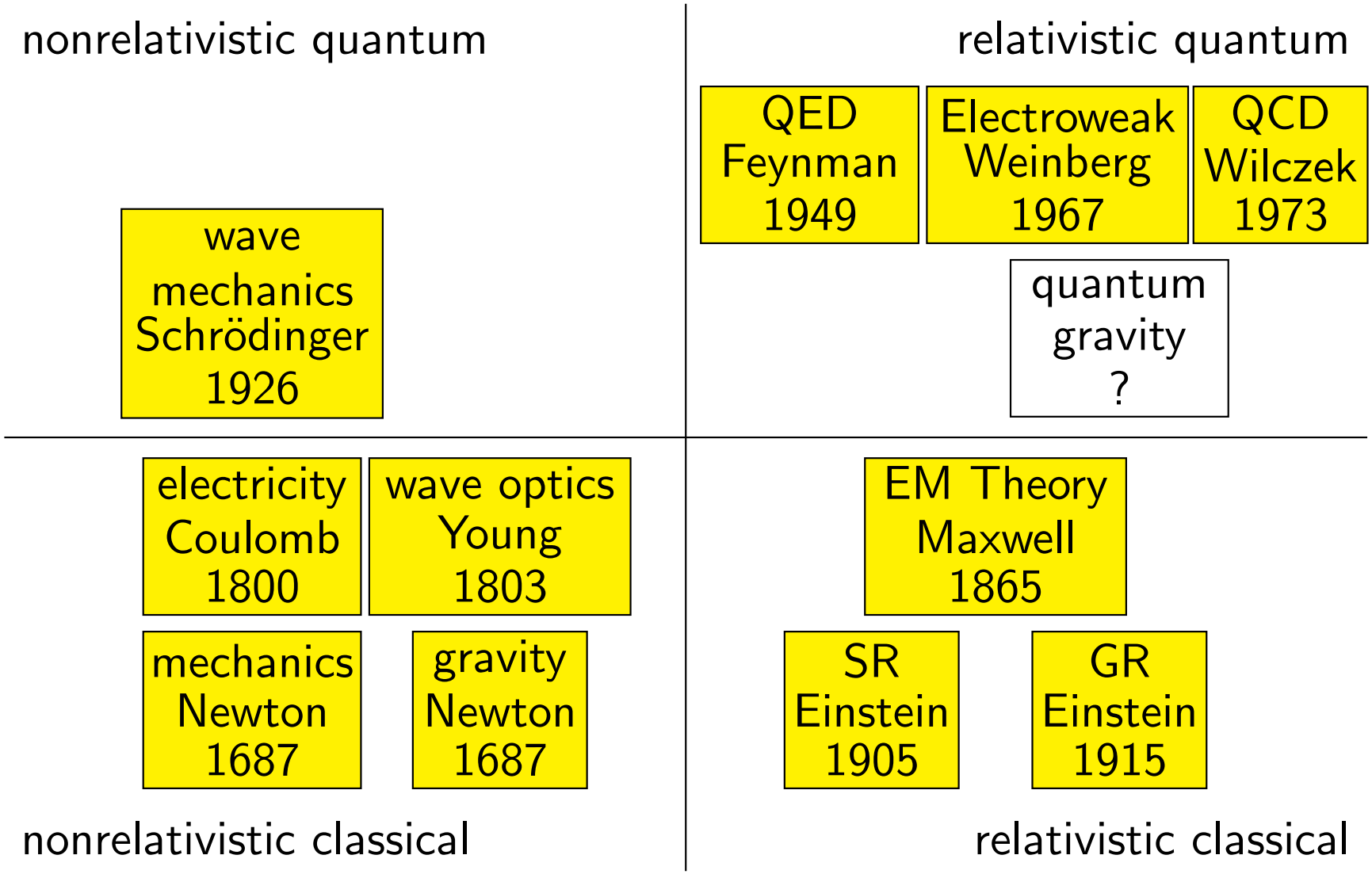
Earth's magnetic field in Annville, PA



Lenz's law

External magnetic flux	Induced magnetic flux	Induced emf
out of board, increasing	into board	clockwise
out of board, decreasing	out of board	counter-clockwise
into board, increasing	out of board	counter-clockwise
into board, decreasing	into board	clockwise

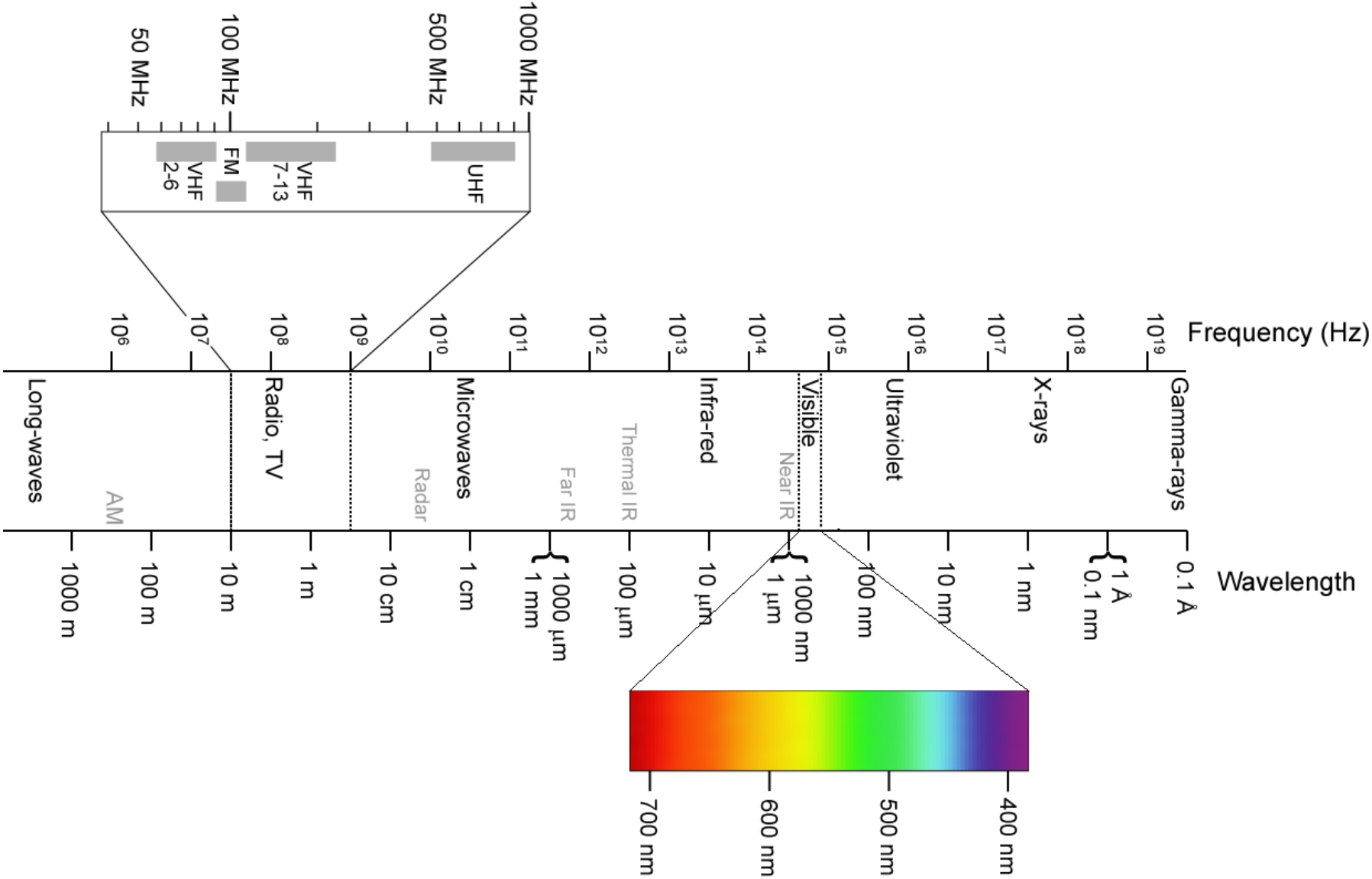
Theories in Physics



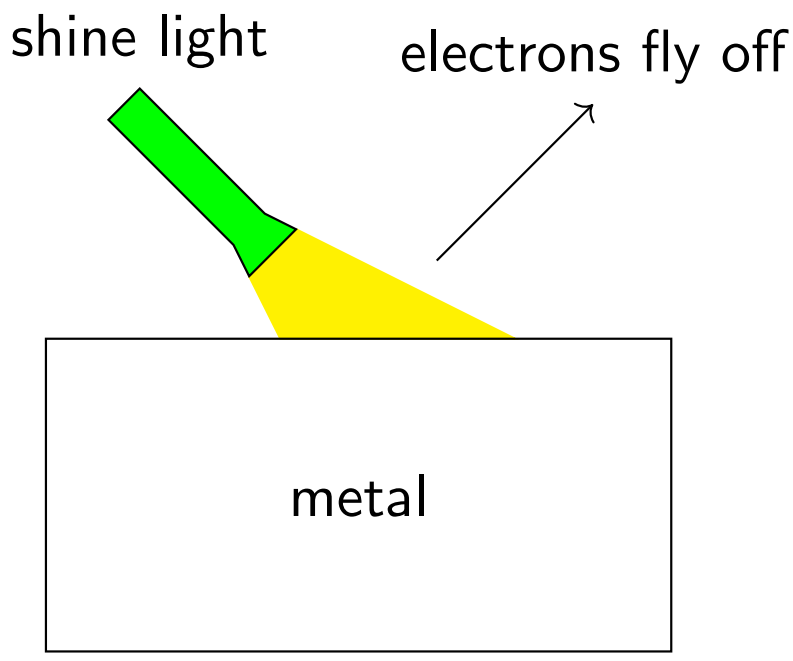
Four theories of light

- Light is a ray
  - Geometrical Optics
- Light is a wave (Young, 1803)
  - Wave Optics
- Light is an electromagnetic wave (Maxwell, 1865)
  - Classical Electromagnetic Theory (EM Theory)
- Light is a quantum field
  - Photon Theory (starting with Planck and Einstein, 1900–1905)
  - QED (Quantum Electrodynamics, 1949)

The electromagnetic spectrum

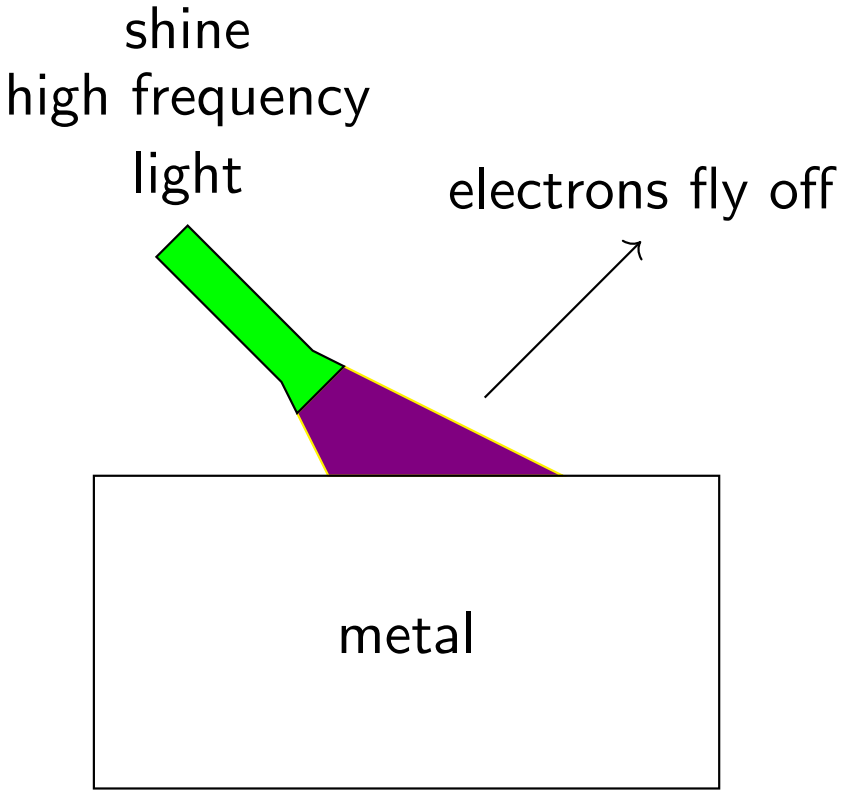


The photoelectric effect

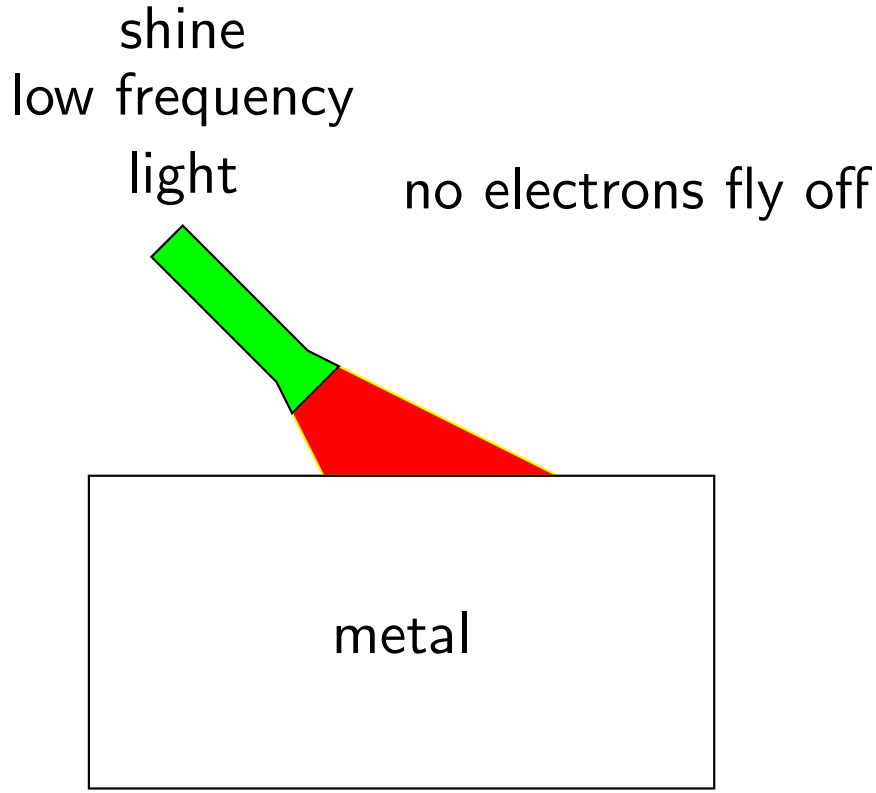


- Light provides the energy needed to free electrons from the metal.

The photoelectric effect



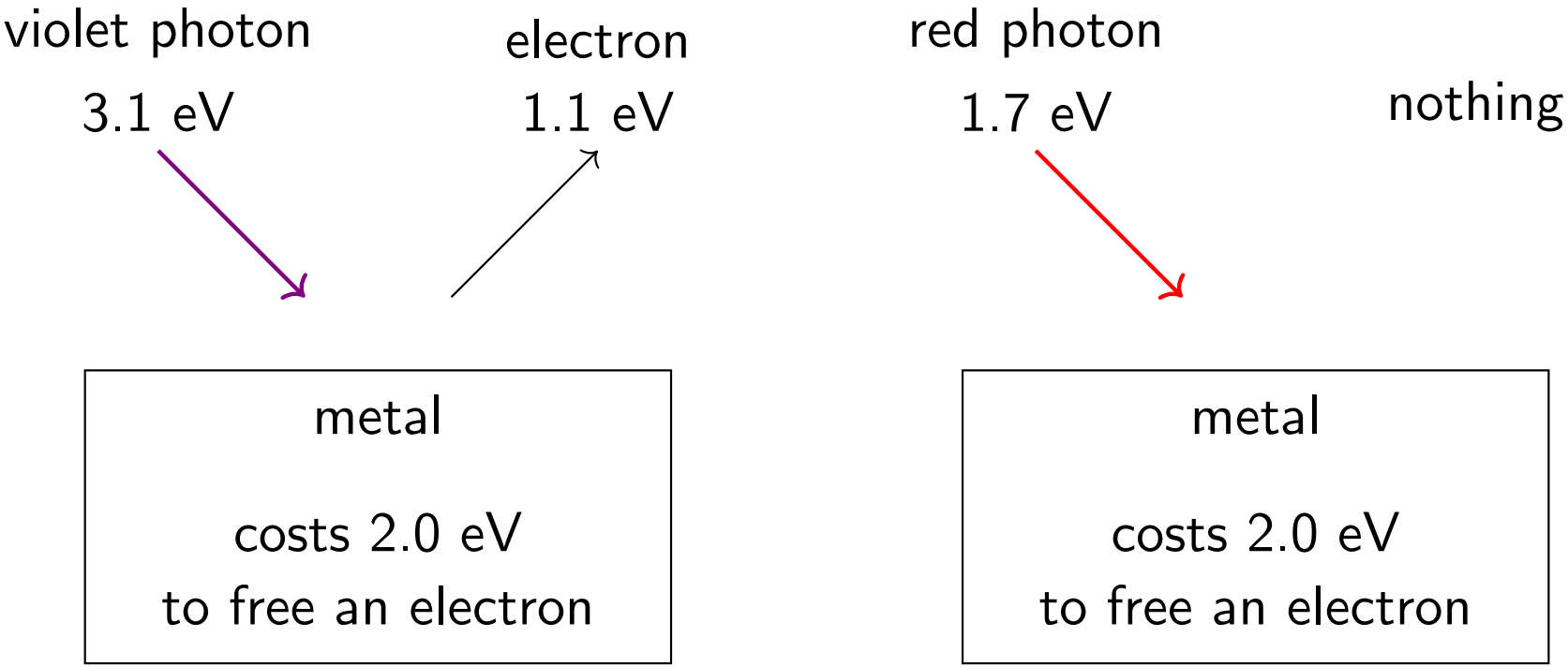
- violet has high frequency



- even if light is very bright

The photoelectric effect: Einstein's idea

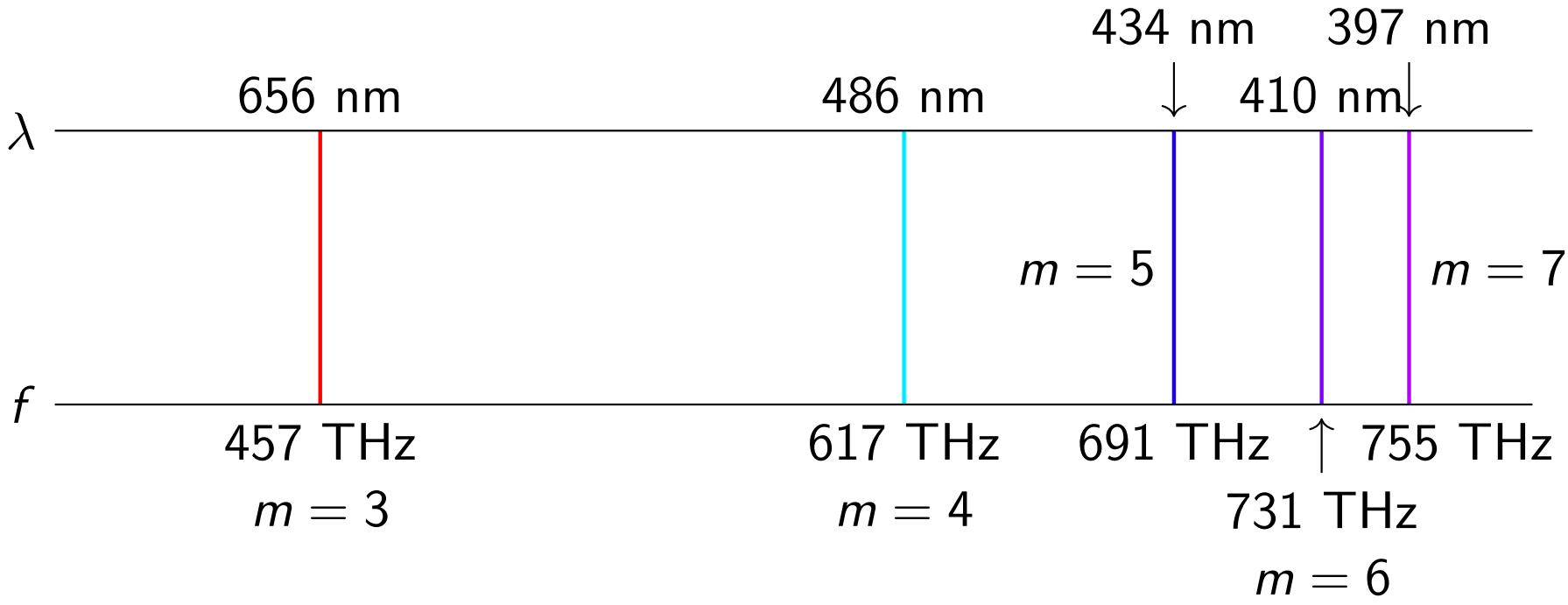
- One photon must free one electron.
- Energy of one photon is $E = hf$.



Key events in the development of Quantum Theory

1900	Planck proposes quanta of light
1905	Einstein explains photoelectric effect
1913	Bohr suggests special radii
1921	Stern and Gerlach demonstrate spatial quantization
1923	Compton sees frequency shift in scattered X-rays
1924	de Broglie suggests matter waves
1925	Heisenberg presents matrix mechanics
1926	Schrödinger presents wave mechanics
1927	Heisenberg presents uncertainty principle

Balmer (1885) looked at 5 lines from hydrogen



He found a pattern:

$$\lambda = \frac{365\ \text{nm}}{1 - \frac{4}{m^2}} \qquad f = 3289\ \text{THz}\left(\frac{1}{2^2} - \frac{1}{m^2}\right)$$

Circumference as a function of velocity

As a model for hydrogen, suppose electron is in uniform circular motion around proton because of Coulomb's law:

$$k\frac{|q_e q_p|}{r^2} = m_e\frac{v^2}{r}$$

Solve for r:

$$r = \frac{k\,|q_e q_p|}{m_e v^2}$$

Circumference is $2\pi r$:

$$C = \frac{2\pi k\,|q_e q_p|}{m_e v^2}$$

Wavelength as a function of velocity

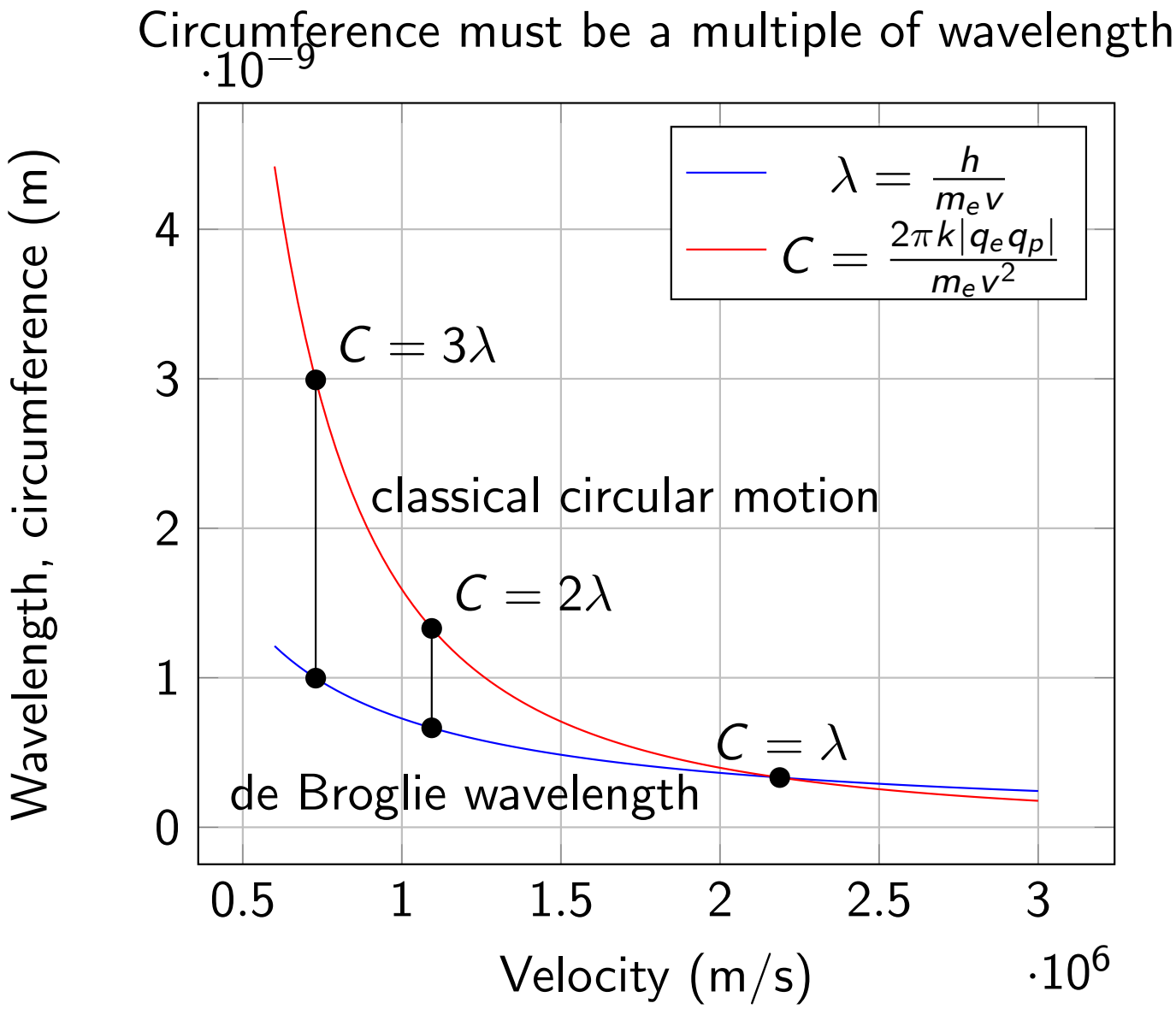
In preparation for Bohr's idea, we use the quantum idea of how momentum is related to wavelength

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

to get an expression for wavelength as a function of velocity. Solve this equation for wavelength and use $m_e v$ for the momentum of the electron.

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

Bohr atom (1913)



Energy of electron in hydrogen

Electron energy consists of kinetic energy and potential energy:

$$E = \frac{1}{2} m_e v^2 + k \frac{q_e q_p}{r}$$

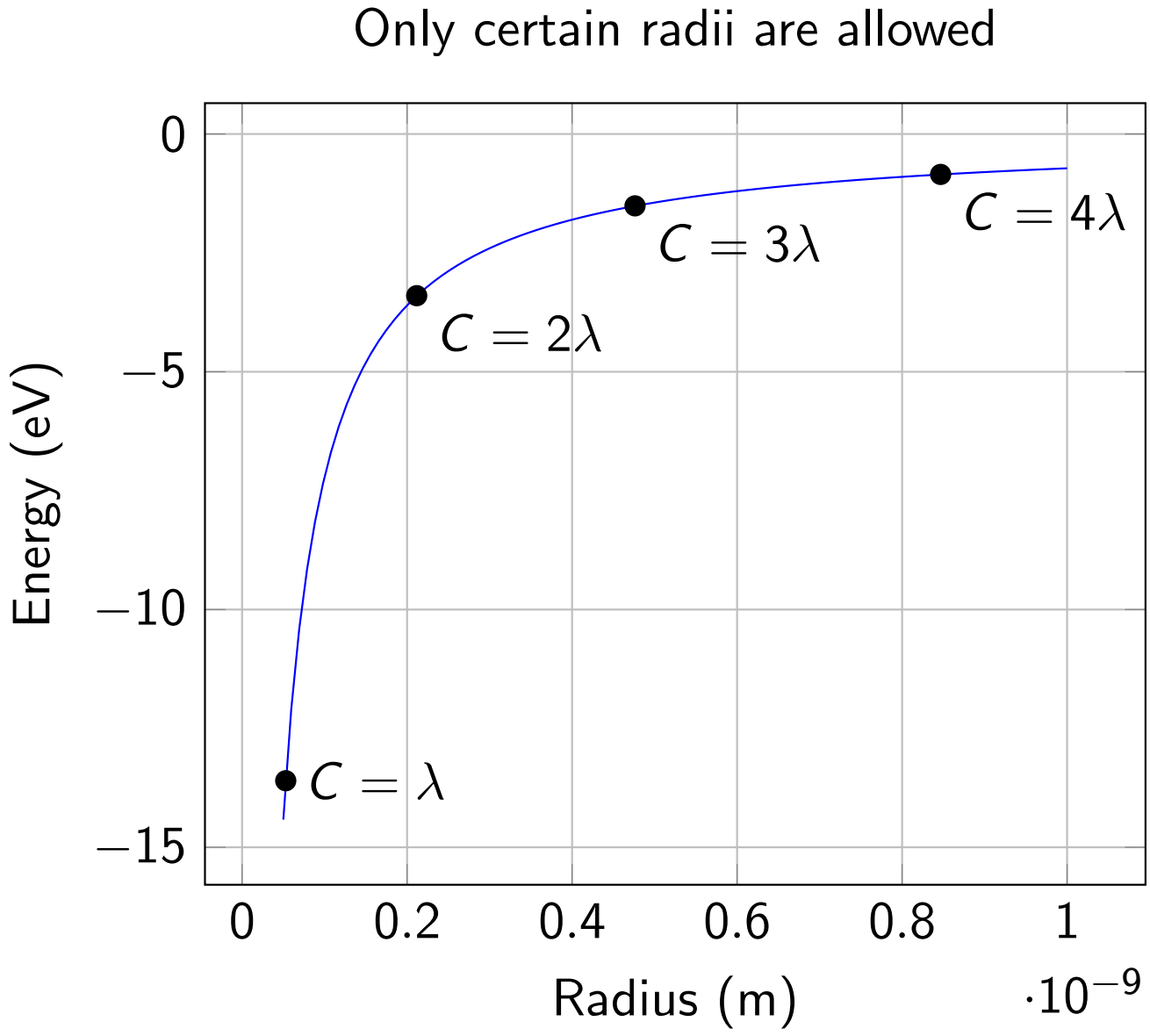
Uniform circular motion equation

$$k \frac{|q_e q_p|}{r^2} = m_e \frac{v^2}{r}$$

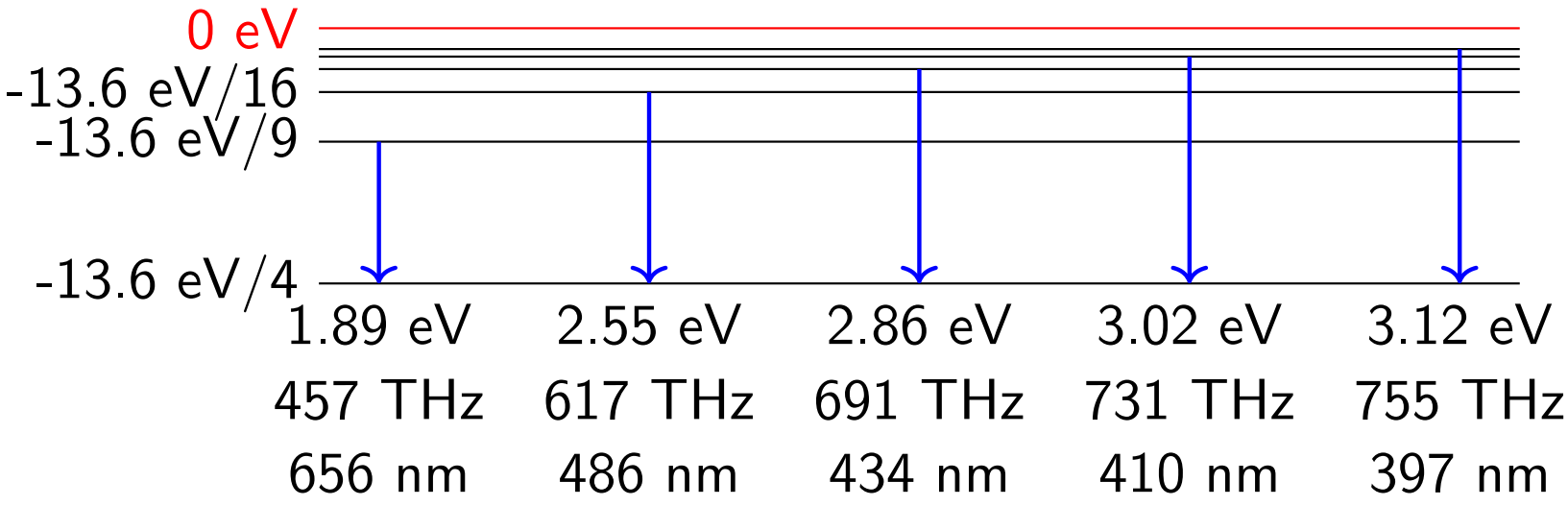
allows us to solve for v in term of r so that we can write E in terms of r.

$$E = \frac{1}{2} k \frac{|q_e q_p|}{r} + k \frac{q_e q_p}{r} = -\frac{1}{2} k \frac{|q_e q_p|}{r}$$

Bohr model produces hydrogen energy levels



Hydrogen energy levels



Differences in energy levels
match the Balmer frequencies