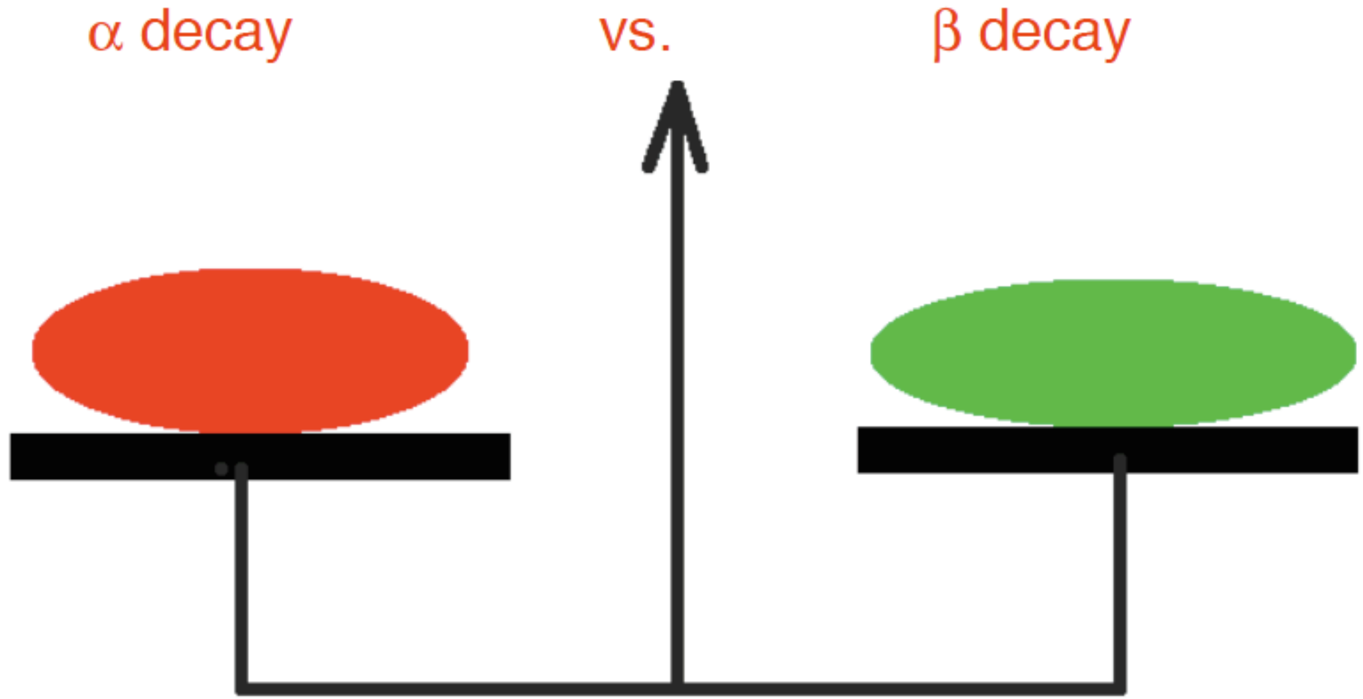


Two radioactive materials are placed on the plates of the balances. Both have the same half-life and initial mass and activity. The red one undergoes α-decay, the green one undergoes β-decay. If we wait long enough the balances

1. do not change 2. lean to the right 3. lean to the left

β

$^{A}_{Z}P \to {}^{0}_{-1}\beta + {}^{??}_{??}D \to A = 0 + ?$

$Z = -1 + ??$

$Z = -1 + ??$

$?? =$

$^{A}_{Z}P \to {}^{0}_{-1}e + {}^{A}_{(Z+1)}D$

$N = A - Z$

$N^{*} = A - (Z+1) =$

$= A - Z - 1$

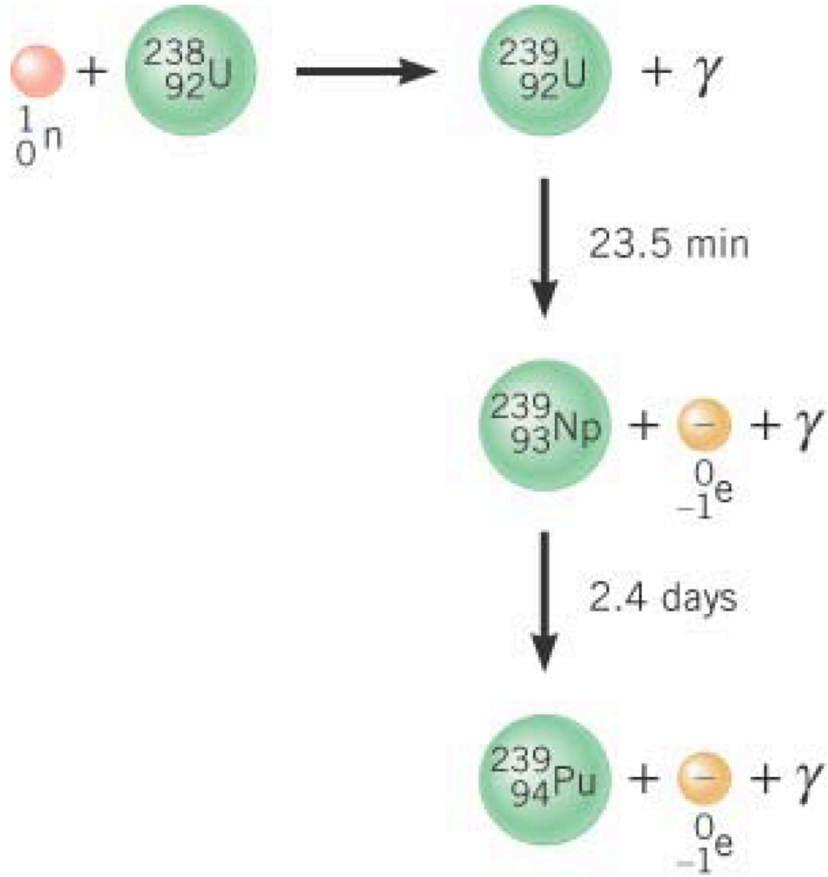
...

1. Yes.

2. No

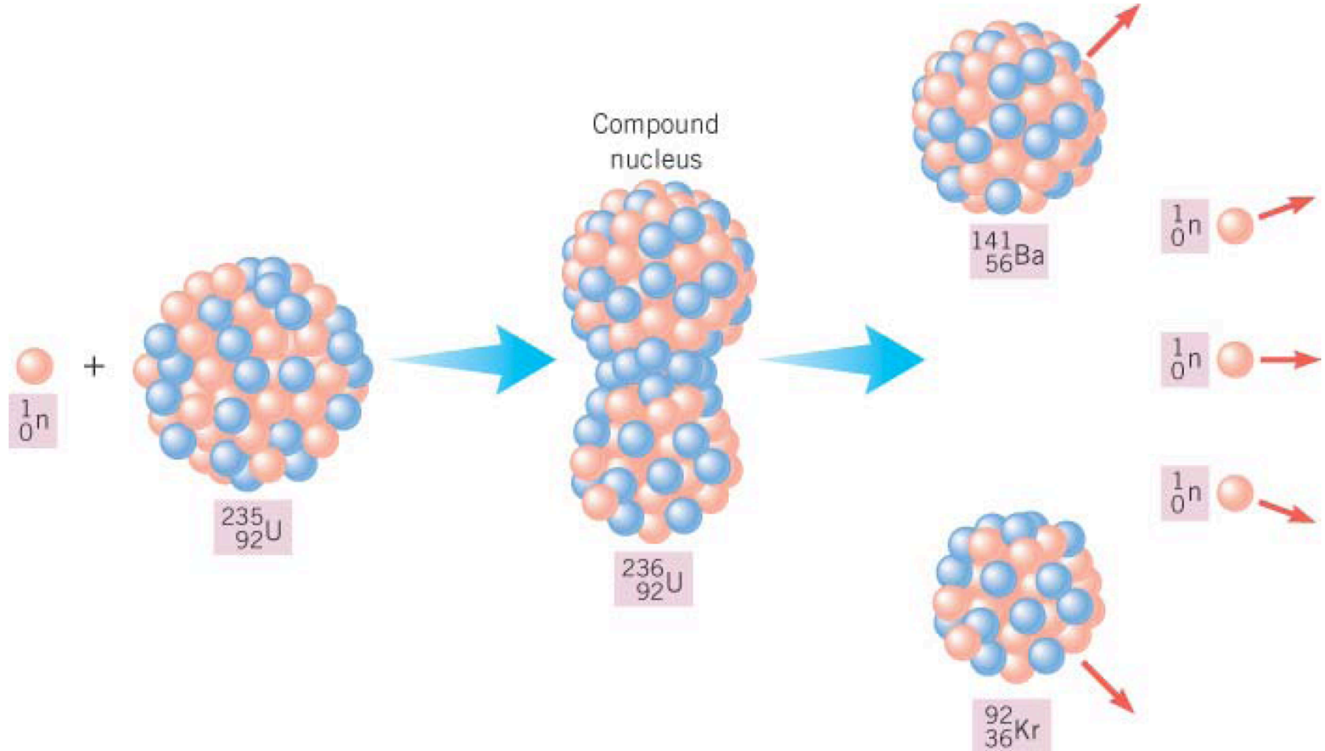
$$ {}^{A}_{Z}P \longrightarrow {}^{4}_{2}\alpha + {}^{A-4}_{Z-2}D $$

Induced Nuclear Reactions



An induced nuclear reaction in which uranium is transmuted into plutonium.

Nuclear Fission

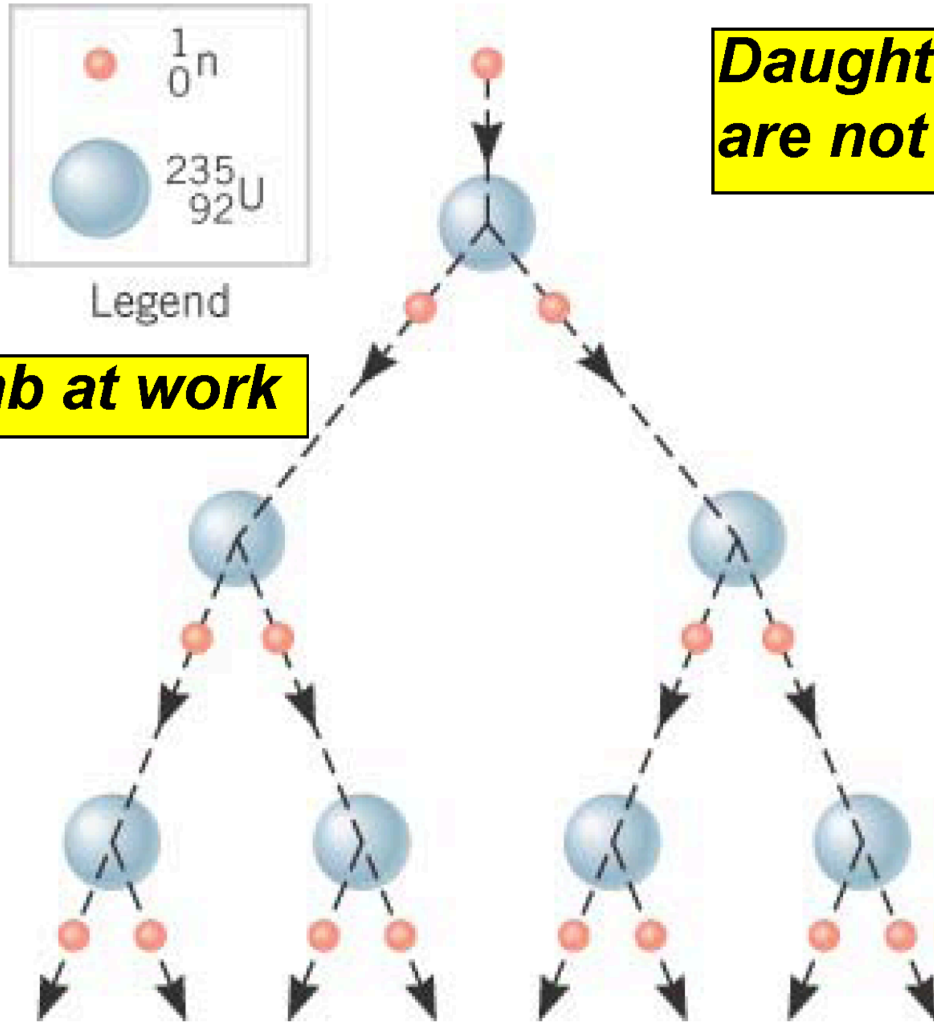


A slowly moving neutron causes the uranium nucleus to fission into barium, krypton, and three neutrons.

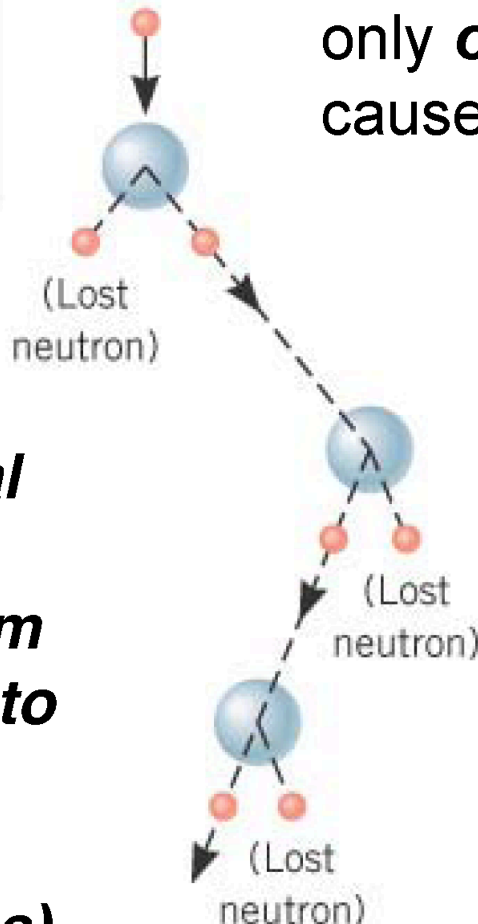
A chain reaction (induced)

Daughter nuclei are not shown.

A U-bomb at work



Legend

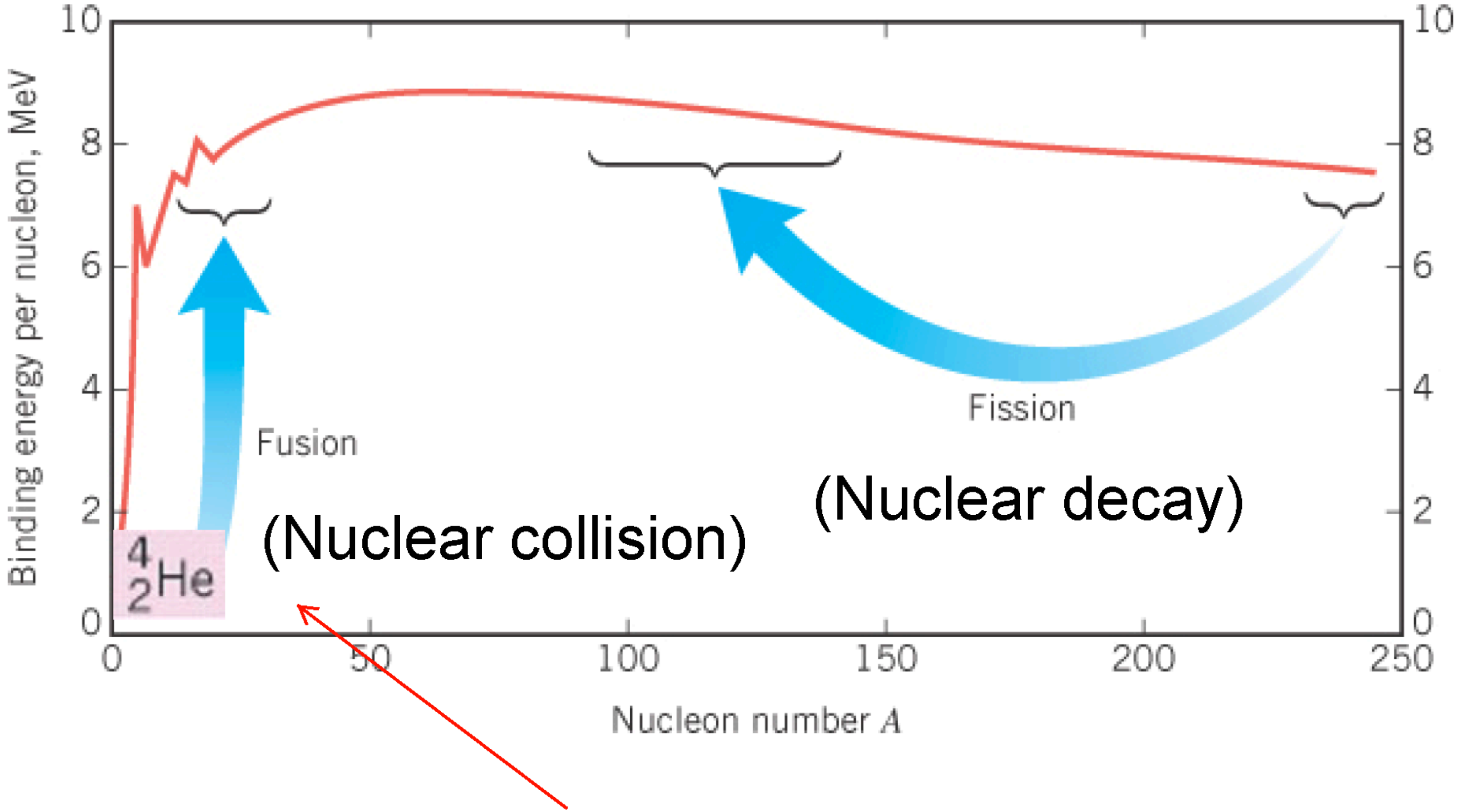


In a ***controlled*** chain reaction, only ***one*** neutron, on average, causes another neutron to fission.

A U-plant at work

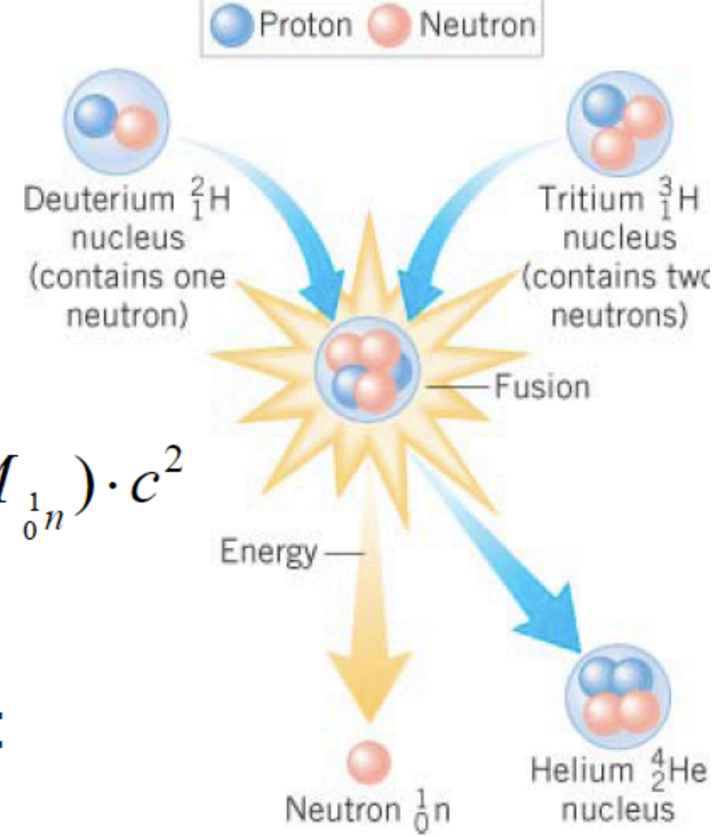
(Material like beryllium is used to absorb extra neutrons)

Daughter nuclei are not shown.



Two nuclei of very low mass can combine to generate energy. This process is called ***nuclear fusion.***

Nuclear Fusion



The energy per one reaction:

$$E_{per-reaction} = (M_{^2_1H} + M_{^3_1H} - M_{^4_2He} - M_{^1_0n}) \cdot c^2$$

The total energy of the fusion:

$$E_{total} = E_{per-reaction} \cdot N_{reactions} = E_{per-reaction} \cdot N_{Deuterium}$$

Where does this energy go?

A two -step picture

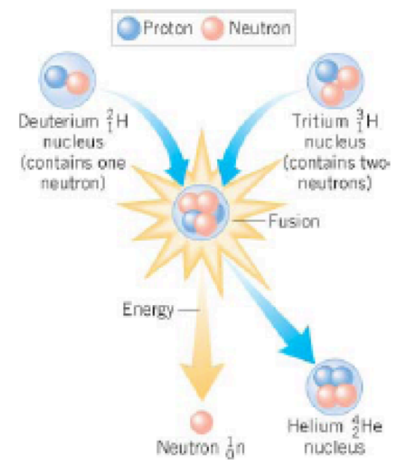
$$^{3}_{1}H + ^{2}_{1}H \rightarrow ^{5}_{2}X \quad => \quad ^{3}_{1}H + ^{2}_{1}H \rightarrow ^{5}_{2}He \rightarrow ^{4}_{2}He + ^{1}_{0}y$$

$$^{3}_{1}H + ^{2}_{1}H \rightarrow ^{5}_{2}He \rightarrow ^{4}_{2}He + ^{1}_{0}n$$

an intermediate state which does not live

$\Downarrow$

$$^{3}_{1}H + ^{2}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$$



2.0141 u + 3.0161 u - 4.0026 u - 1.0087 u = 0.0189 u > 0 !

A two -step picture

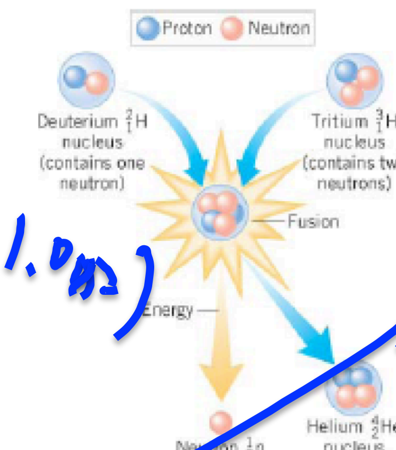
$$^{3}_{1}H + {}^{2}_{1}H \rightarrow {}^{5}_{2}X \quad \Rightarrow \quad ^{3}_{1}H + {}^{2}_{1}H \rightarrow {}^{5}_{2}He \rightarrow {}^{4}_{2}He + {}^{1}_{0}y$$

$$^{3}_{1}H + {}^{2}_{1}H \rightarrow {}^{5}_{2}He \rightarrow {}^{4}_{2}He + {}^{1}_{0}n$$

an intermediate state which does not live

$$\Downarrow$$

$$^{3}_{1}H + {}^{2}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n$$



2.0141 u + 3.0161 u - 4.0026 u - 1.0087 u = 0.0189 u > 0 !

$$1\,u = \frac{1}{12} m_{{}^{12}_{6}C} = 1.006 \times 10^{-27}\,kg$$

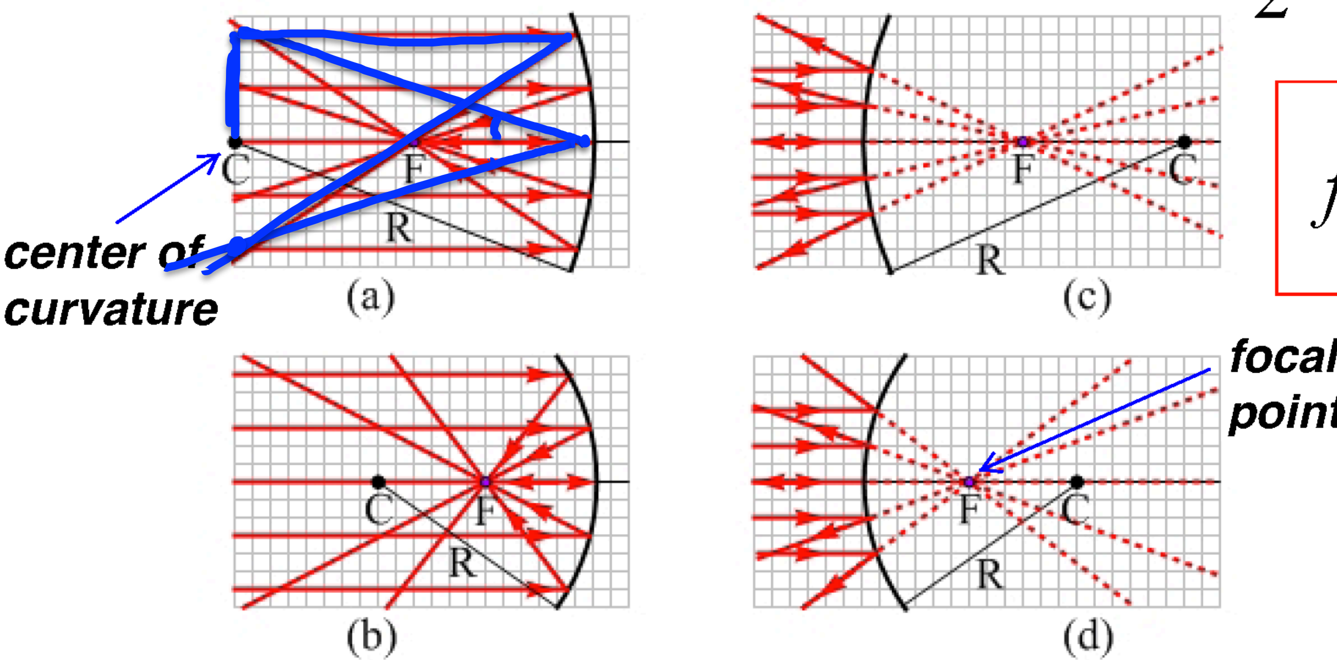
$$E = mc^2$$

$$\Downarrow$$

$$931.5\,MeV = 1\,u$$

Spherical mirrors

The focal length of a spherical mirror : $|f| = \dfrac{R}{2}$



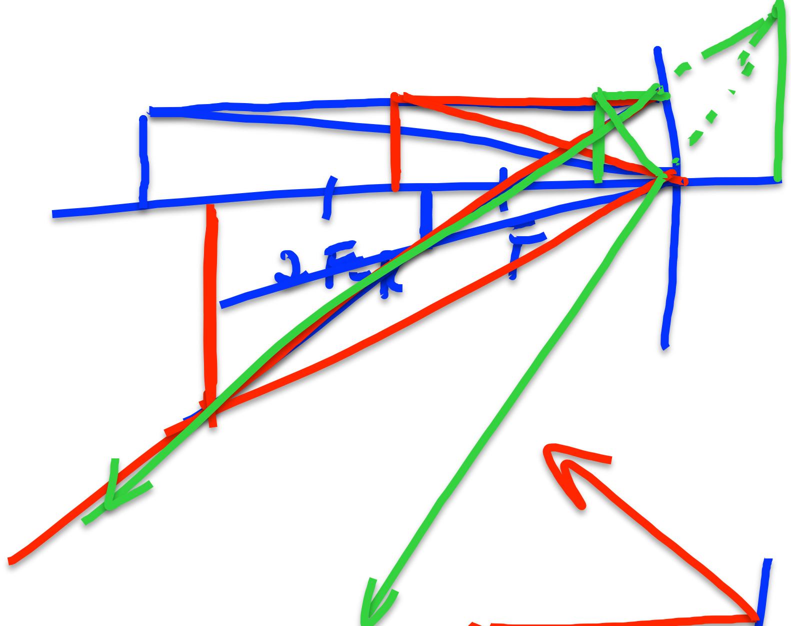
$$f = \pm \frac{R}{2}$$

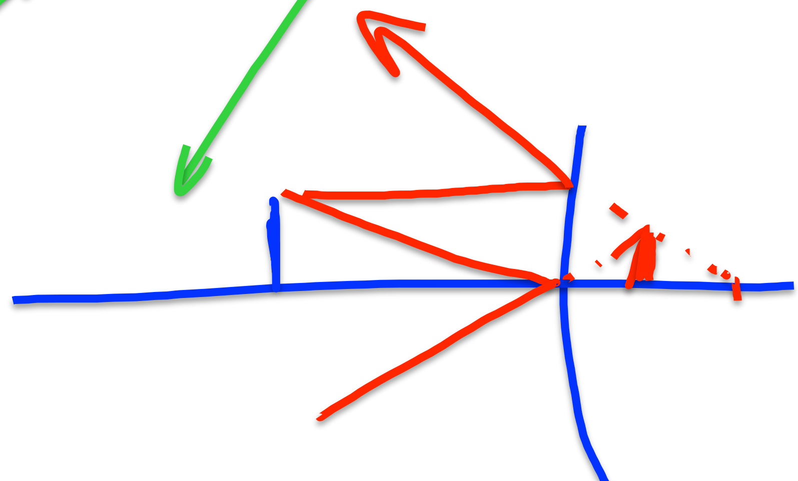
Concave

(positive f)

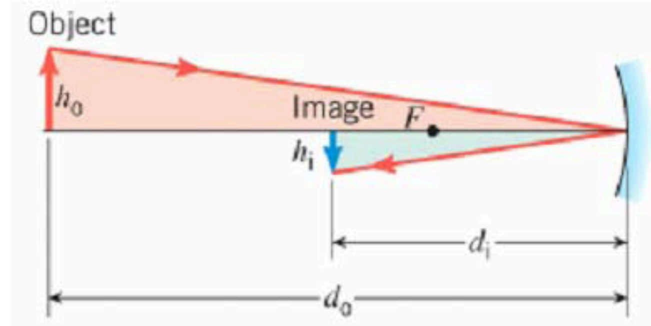
Convex

(negative f)


2F
F



Summary of Sign Conventions for Spherical Mirrors



f is + for a concave mirror.

f is − for a convex mirror.

d_o is + (the object is in front of the mirror)

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

d_i is + if the image is in front of the mirror (real image).

d_i is − if the image is behind the mirror (virtual image).

m is + for an upright image

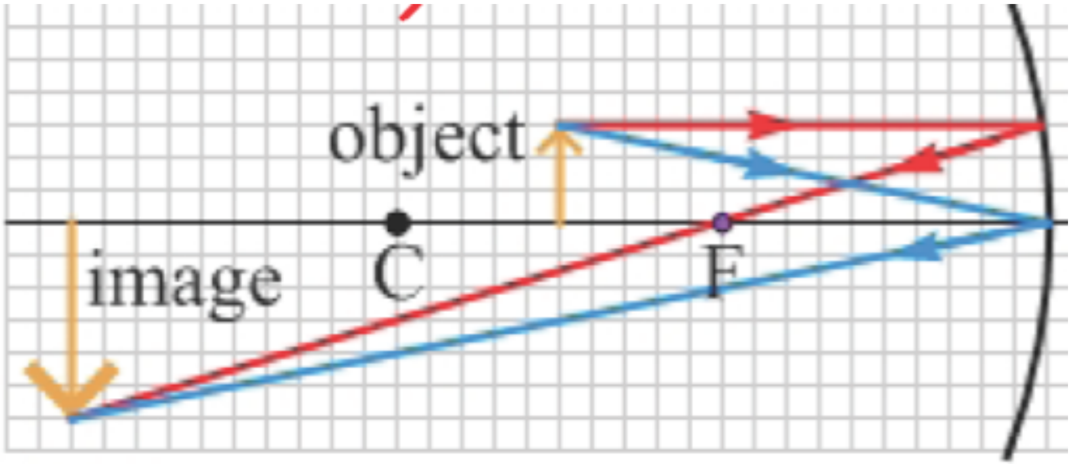
m is − for an inverted image

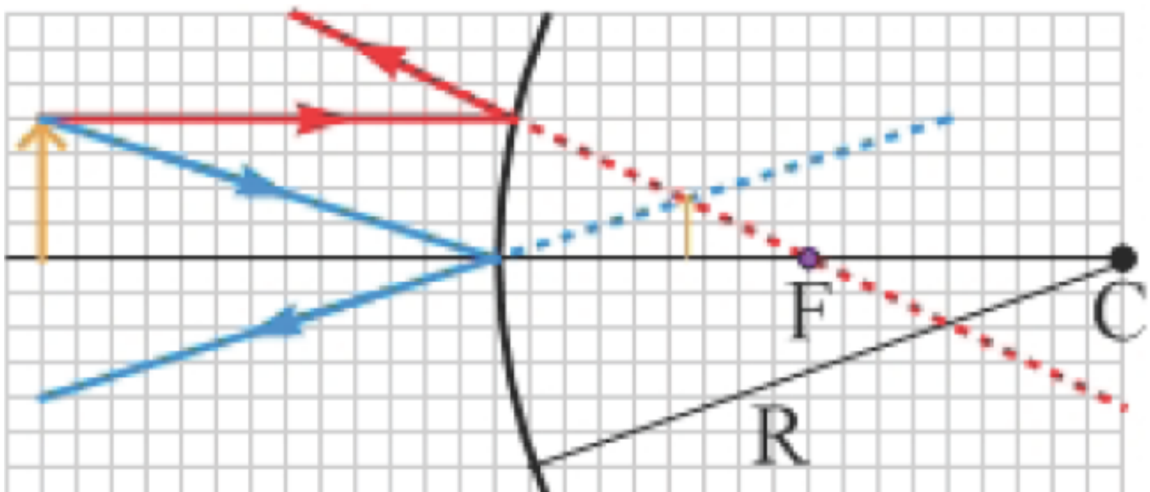
(assuming the object is upright)

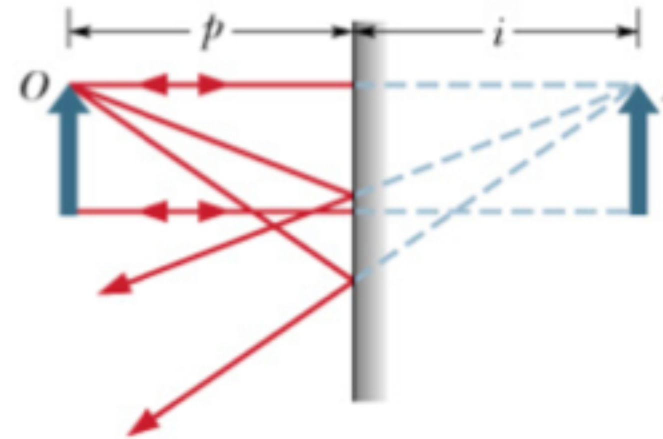
$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

$h_{i,o}$ is + for an upright object. /image

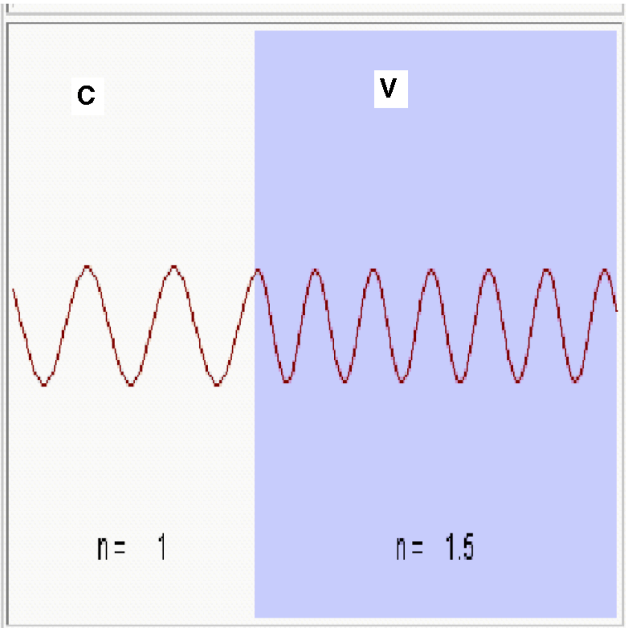
$h_{i,o}$ is − for an inverted object /image


object
image
C
F


F
C
R


p
i
O
I

Light in a medium



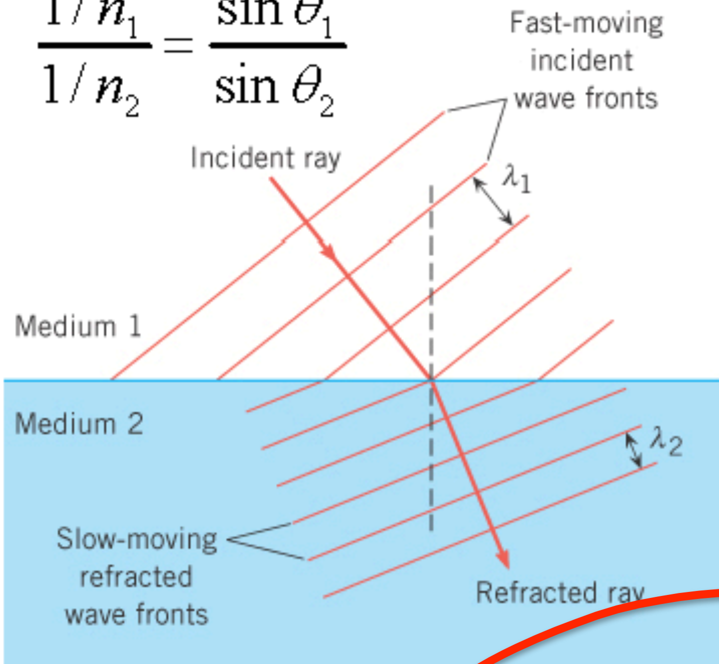
In vacuum	In medium
c – speed of light	v – speed of light; v < c
λ – wavelength	λ_n – wavelength; $\lambda_n < \lambda$
f – frequency	f – frequency (the same!)
$c = \lambda f$	$v = \lambda_n f$
	n – index of refraction
	$n = c/v$
	$\lambda_n = \lambda/n$

THE DERIVATIN OF SNELL'S LAW

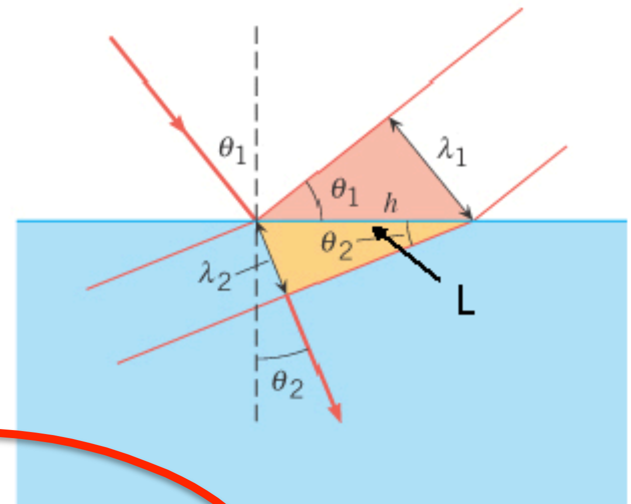
$$v_1 = \frac{\lambda_1}{T} \quad v_2 = \frac{\lambda_2}{T} \quad \Rightarrow \quad \frac{\lambda_1}{v_1} = T = \frac{\lambda_2}{v_2} \quad \Rightarrow \quad \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} = \frac{L\sin\theta_1}{L\sin\theta_2} \quad \Rightarrow \quad \frac{v_1/c}{v_2/c} = \frac{\sin\theta_1}{\sin\theta_2}$$

$$\frac{1/n_1}{1/n_2} = \frac{\sin\theta_1}{\sin\theta_2}$$

$$\frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2}$$

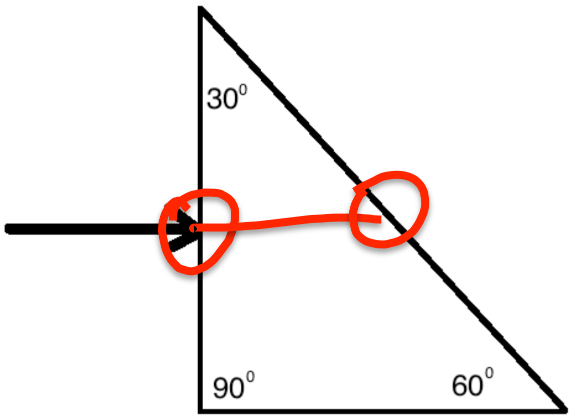


(a)

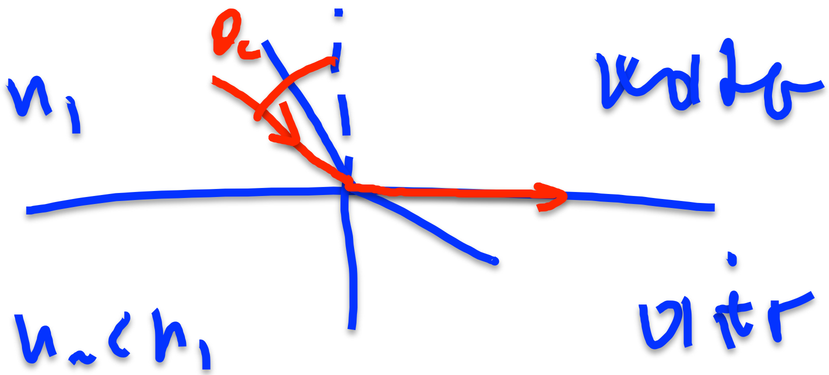


(b)

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$



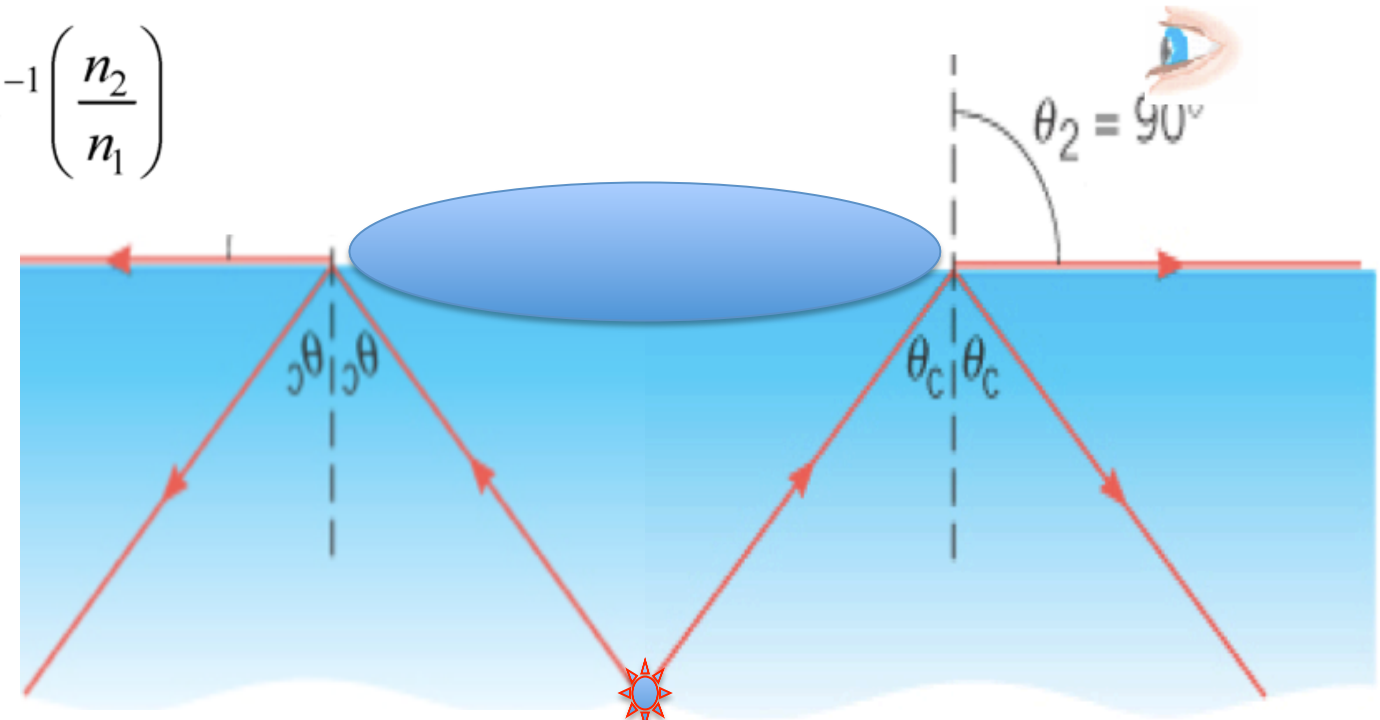
a beam of light enters a prism as shown in the diagram on the left. The index of refraction of the material of the prism is n = 1.7. Find the angle at which the light **exits** the prism (measured from its original direction).

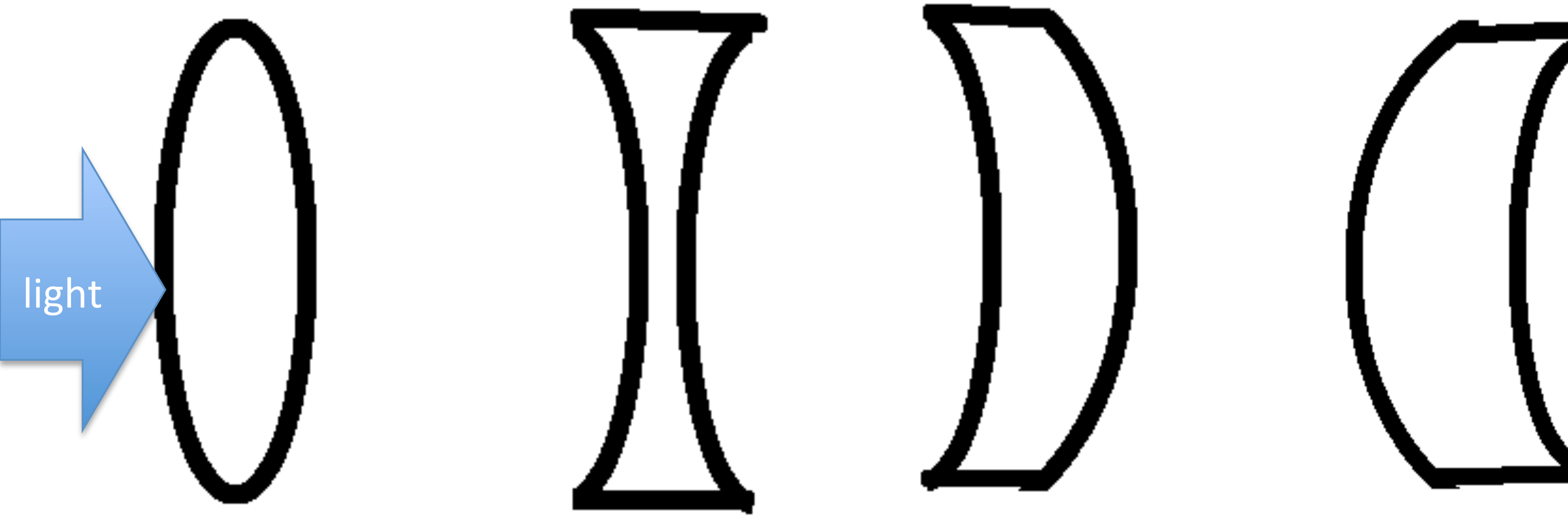


$\sin\theta_1 = \frac{n_2}{n_1}$

A light-bulb is 2 m below the surface of water (n = 1.33). What is the radius of the bright circle on the surface of the water?

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

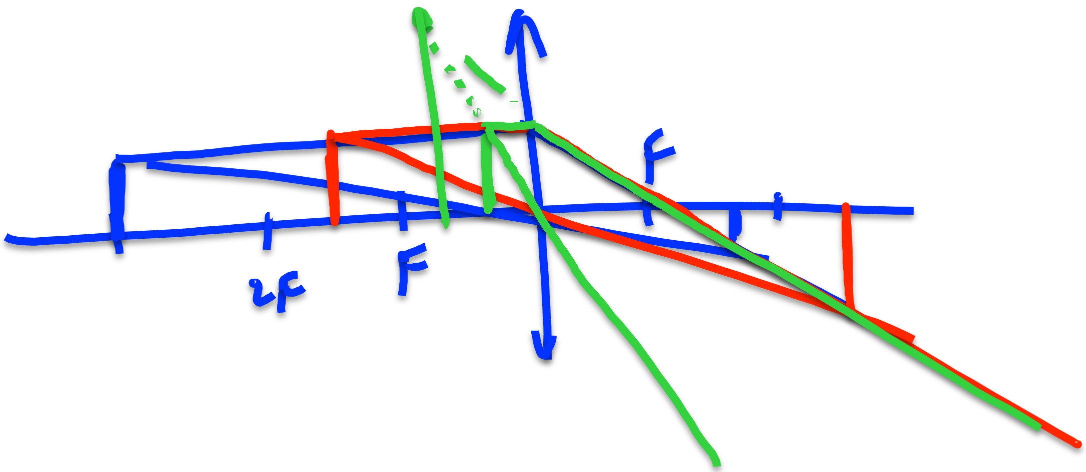


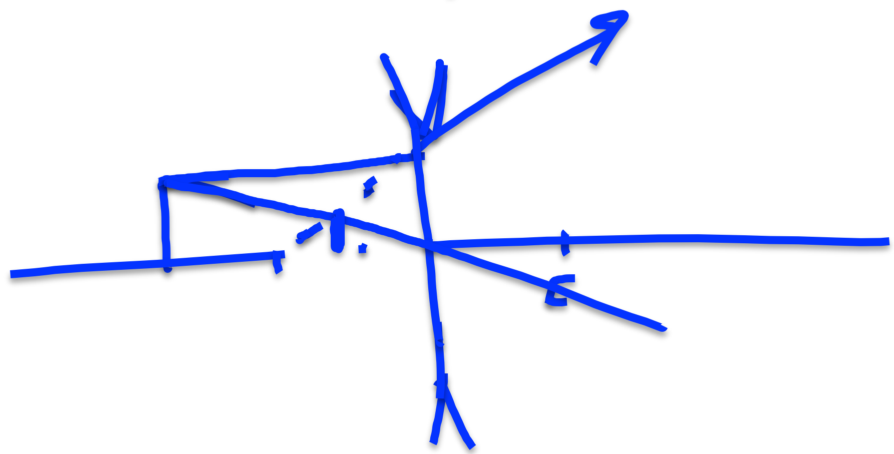


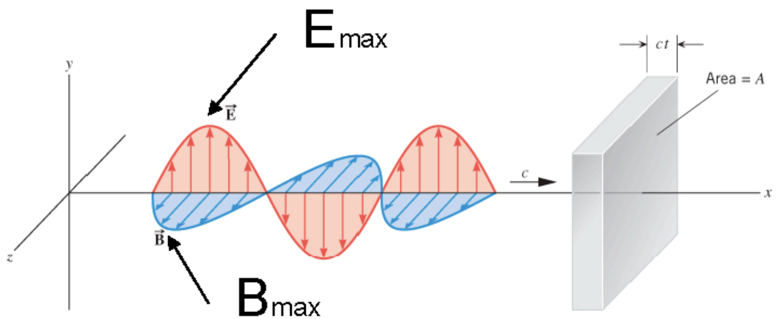
(by-convex) (by-concave)

$R_1>0$ $R_2<0$ $R_1<0$ $R_2>0$ $R_1<0$ $R_2<0$ $R_1>0$ $R_2>0$

$$\frac{1}{f}=\left(\frac{n_{lens}}{n_{medium}}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$


2F
F
F





Instantaneous intensity

$$I = cu$$

Instantaneous energy density

$$u = \frac{EB}{\mu_o c}$$

Instantaneous intensity $I = \dfrac{EB}{\mu_0}$

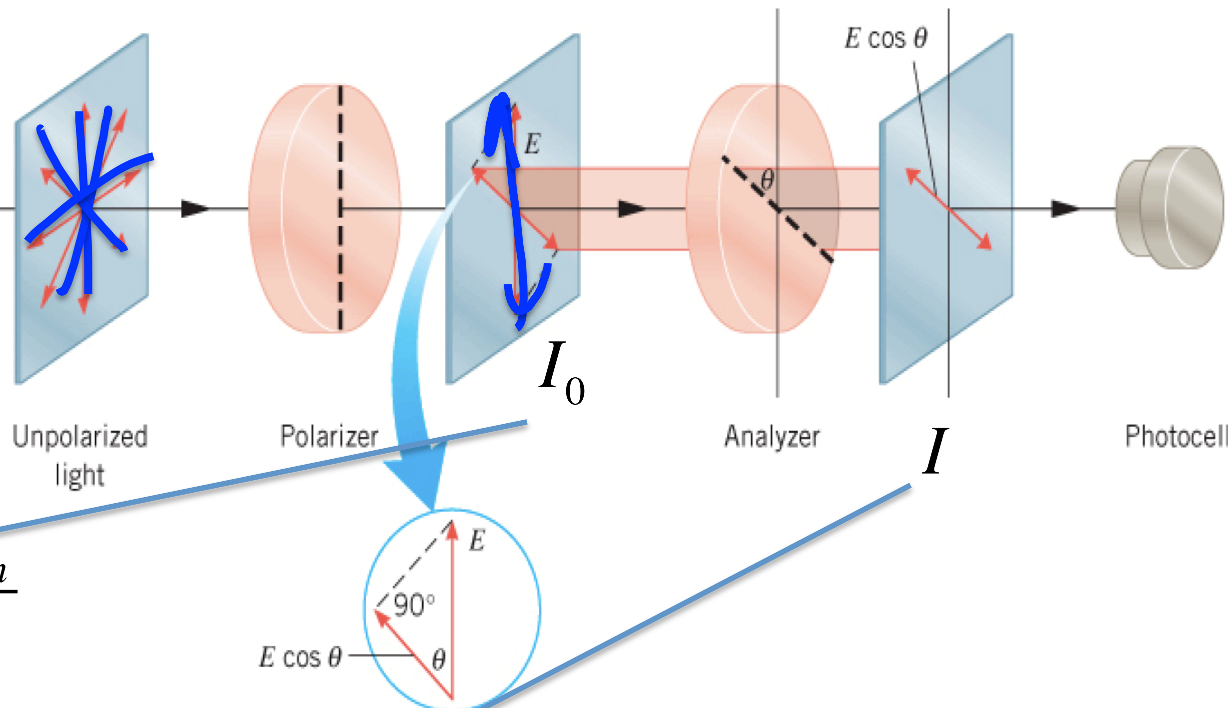
$$I \sim \frac{P}{4\pi r^2}$$

$I_{\min} = 0$ $\quad I_{\max} = \dfrac{E_{\max} B_{\max}}{\mu_0} \rightarrow I_{ave} = \dfrac{P_{ave}}{A}$ is somewhere in between

Irradiance =
Average intensity

$$I_{ave} = \frac{1}{2} \cdot \frac{E_{\max} B_{\max}}{\mu_0} = \frac{E_{\max} B_{\max}}{2\mu_0}$$

A combination of polarizers



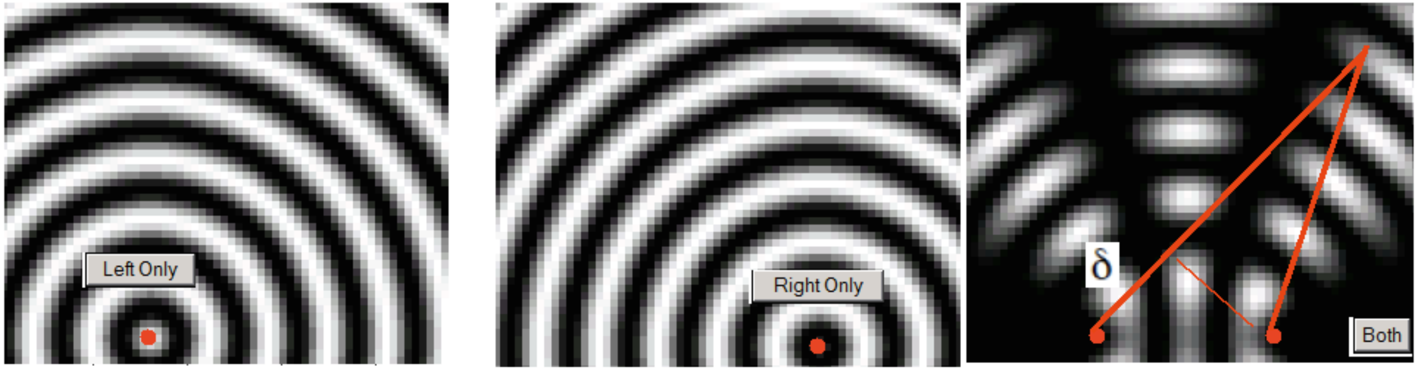
$$I_0 = \frac{I_{un}}{2}$$

MALUS' LAW

$$I = I_o \cos^2 \theta$$

intensity after analyzer

intensity before analyzer



2-D standing wave!

Conditions for interference

When waves come together they can interfere constructively or destructively. To set up a stable and clear interference pattern, two conditions must be met:

1. The sources of the waves must be ***coherent***, which means they emit identical waves with a constant phase difference.
2. The waves should be ***monochromatic*** - they should be of a single wavelength.

Let's say we have two sources sending out identical waves in phase. Whether constructive or destructive interference occurs at a point near the sources depends on the path-length difference, δ, which is the distance from the point to one source minus the distance from the point to the other source.

Condition for constructive interference: $\delta = m\lambda$, where m is any integer.

$m = 0, 1, 2, 3, 4$

Condition for destructive interference: $\delta = (m - 1/2)\,\lambda$

$m = 1, 2, 3, 4$

$\delta = \Delta r = |r_1 - r_2| > 0$ - **path length difference**

1000 per cm

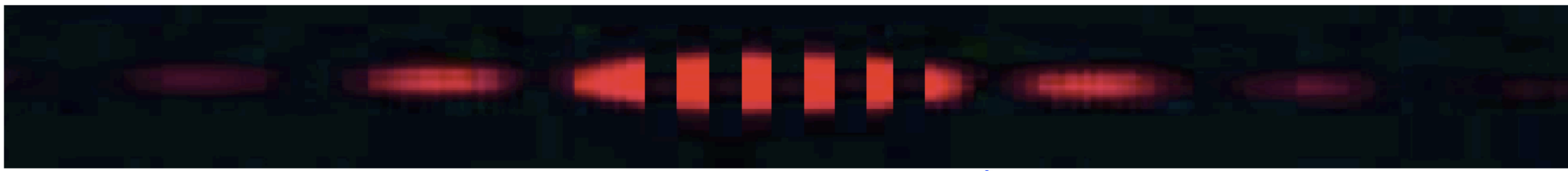
A diffraction grating interference pattern

$d = \frac{1\,cm}{1000}$

$\delta = m\lambda$

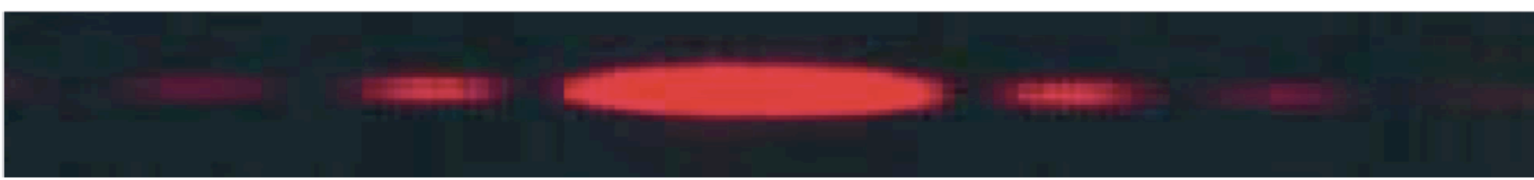
$d \cdot \sin\theta = m\lambda$

A double slit interference pattern



$\leftrightarrow d$

A single slit interference pattern



Geometry:

$\tan\theta = y/L$

L – the distance from the slit(s) to the screen

$m = 0,1,2,\ldots$ order number

Θ – an angular position of a maximum or a minimum

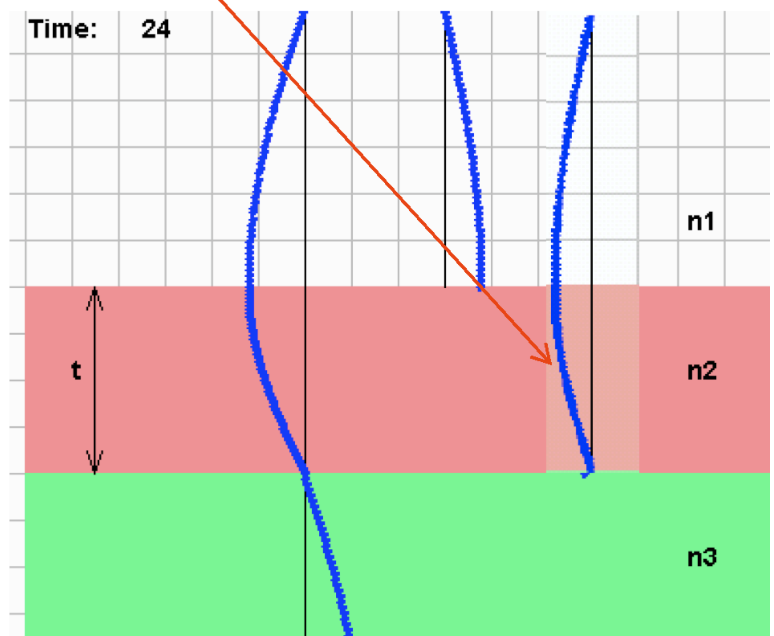
A single slit	Two slits or sources	A grating
Minimum: $w\sin\theta = m\lambda$ Notations: l – the distance from the center to the m-th minimum w – the size of the slit $m = 1,2,\ldots$	Maximum: $m = 0,1,2,$ $d\sin\theta = m\lambda$ Minimum: $m = 1,2,\ldots$ $d\sin\theta = (m - 1/2)\lambda$ Notations: d – the distance between the slits	Principal Maximum: $d\sin\theta = m\lambda$ $d = 1/N$ $m = 0,1,2,$ N – the number of slits per a unit length

Step 5

Step 5 – Solve for the minimum film thickness.

$$2t_{\min} = \frac{1}{2}\lambda_{film} \quad \Rightarrow \quad t_{\min} = \frac{1}{4}\lambda_{film} = \frac{1}{4}\frac{\lambda}{n} = \frac{\lambda}{4n}$$

$$t_{\min} = \frac{600\text{ nm}}{4 \cdot 1.5} = 100\text{ nm}$$



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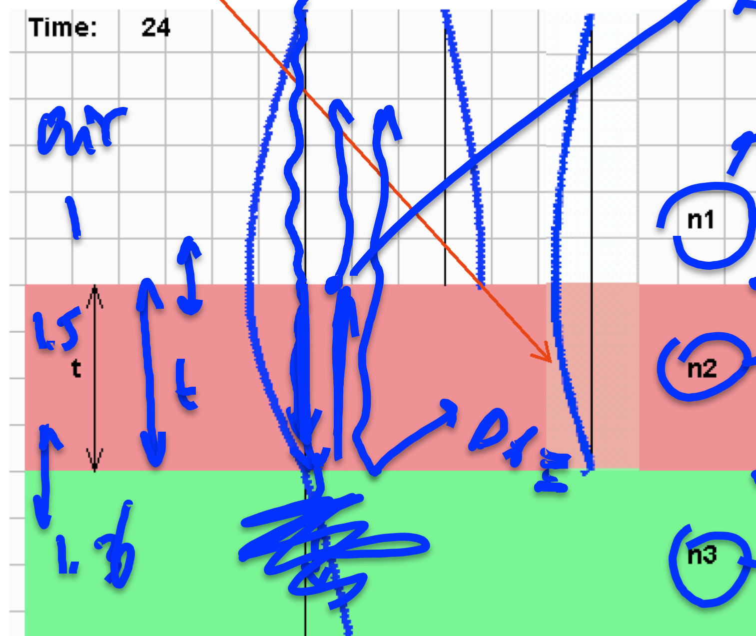


$$2t + |\Delta_t - \Delta_b| = m\lambda$$ **Bright**

$m = 0, 1, 2, 3, 4$

or

$$2t + |\Delta_t - \Delta_b| = \left(m - \frac{1}{2}\right)\lambda$$ **Dark**

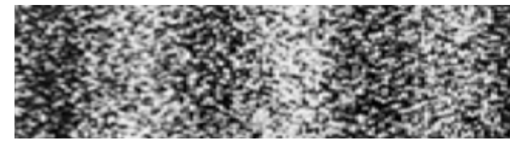
$m = 1, 2, 3, 4, \ldots$

The de Broglie wavelength

$E_{ph} = \frac{1240\ eV\cdot nm}{\lambda}$

From experiments on diffraction of electrons and other small particles is found that to every object of mass having the momentum *p* we can assign a wavelength λ

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



The universal constant $h = 2\pi \cdot 1.0546 \cdot 10^{-34}\ \mathrm{J \cdot s}$

or $h = 6.626 \times 10^{-34}\,\mathrm{J \cdot s}$

is named as Plank’s constant.

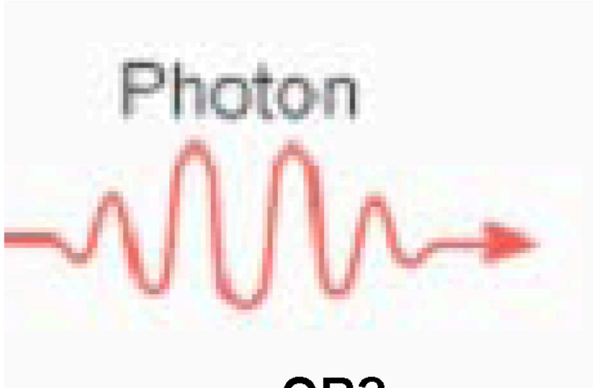
Its value is so small that the wave-like properties of objects cannot be measured for large objects, even like a droplet of dust.

Photons

The speed of light is v = c !

Momentum is $p = mv = mc$

$$\lambda = \frac{h}{mc} \qquad m = \frac{h}{\lambda c} \quad !$$

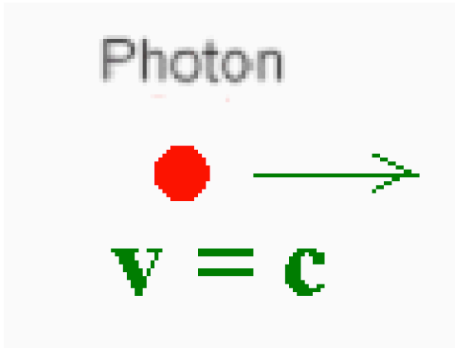


OR?

$$E = mc^2$$

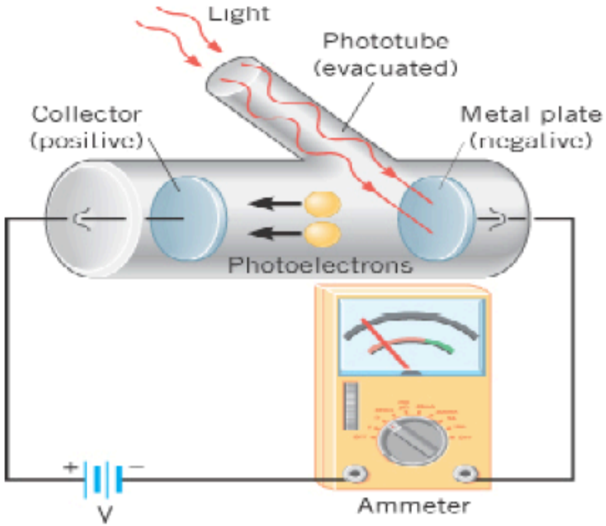
(Another famous equation from Einstein!)

$$E_{light} = \frac{h}{\lambda c}c^2 = \frac{hc}{\lambda} = hf$$



Both!

Stopping potential



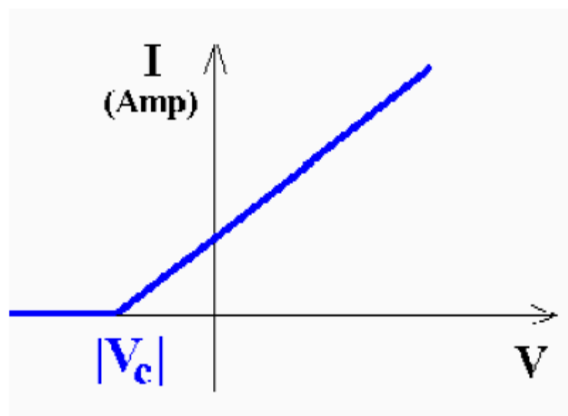
$$hf = W_0 + K_{max}$$

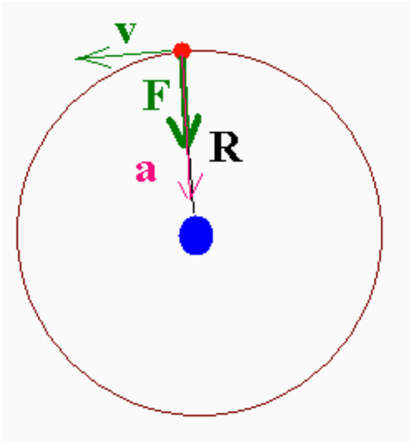
$$I = N^*E_{photon} = hf\,\mathbf{N}$$

For a case $f > W_o/h$ and f = const:

changing the voltage changes the current.

$$e \cdot |V_c| = K_{max}$$





The Bohr Model

$$E = -k\frac{e^2}{2R}$$

$$p = mV = e\sqrt{\frac{km}{R}}$$

$$L = pR = e\sqrt{kmR}$$

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

$$2\pi R = n \cdot \lambda, \quad n = 1, 2, 3, 4, \ldots$$

We can solve this system of equation and get this!

$$p = \frac{2\pi k e^2 m}{h \cdot n}$$

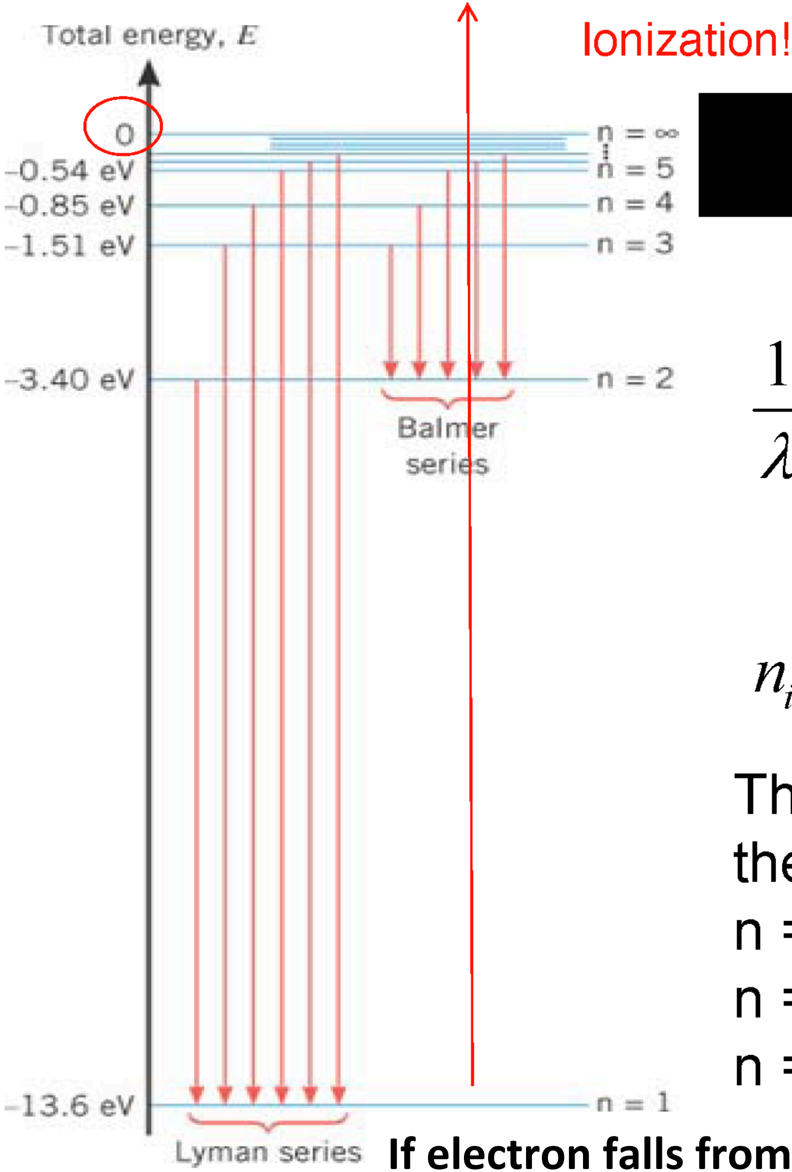
$$L = n\frac{h}{2\pi}$$

$$R = \frac{h^2}{4\pi^2 k m e^2} n^2$$

$$E = -\frac{2\pi^2 k^2 m e^4}{h^2} \cdot \frac{1}{n^2}$$

Everything is quantized!

(What about K or U?)



$$\frac{1}{\lambda} = \frac{2\pi^2 m k^2 e^4}{h^3 c}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$n_i, n_f = 1, 2, 3, \ldots \qquad n_i > n_f$$

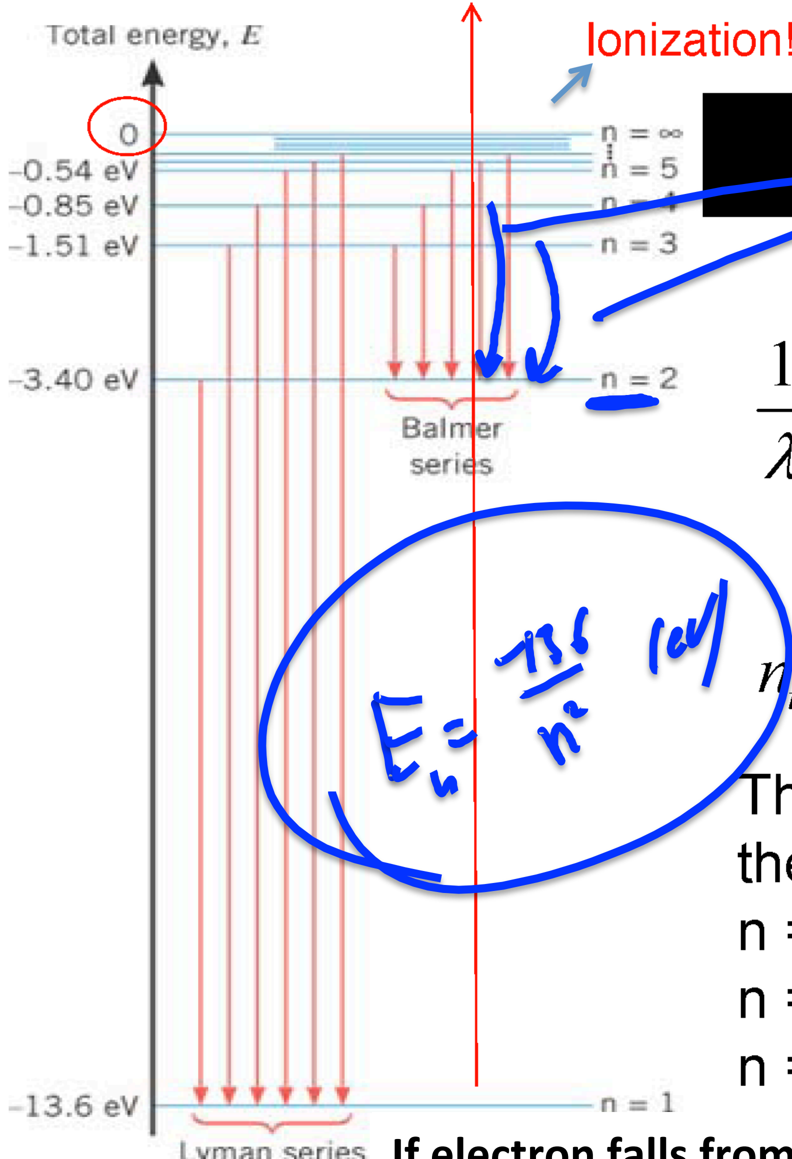
The first three wavelengths in the Balmer series are:

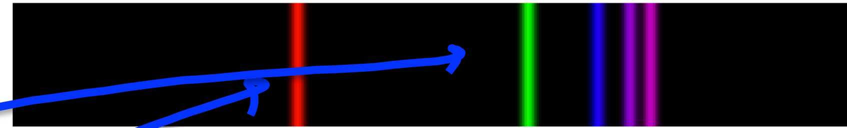
n = 3, l = 656 nm

n = 4, l = 486 nm

n = 5, l = 434 nm

If electron falls from 4th level, how many lines can be generated?





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If electron falls from 4th level, how many lines can be generated?

Radioactive Decay and Activity

$$R = \lambda N = R_0 e^{-\lambda t}$$

$$N = \frac{N_0}{2^n}$$

$$N = N_0 2^{-n}$$

$$n = \frac{t}{T_{1/2}}$$

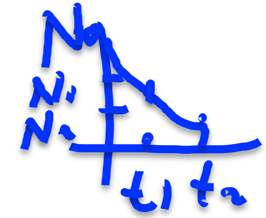
$$\lambda = \frac{\ln 2}{T_{1/2}}$$

Some Half-Lives for Radioactive Decay

Isotope		Half-Life
Polonium	$^{214}_{84}Po$	1.64×10^{-4} s
Krypton	$^{89}_{36}Kr$	3.16 min
Radon	$^{222}_{86}Rn$	3.83 d
Strontium	$^{90}_{38}Sr$	29.1 yr
Radium	$^{226}_{88}Ra$	1.6×10^{3} yr
Carbon	$^{14}_{6}C$	5.73×10^{3} yr
Uranium	$^{238}_{92}U$	4.47×10^{9} yr
Indium	$^{115}_{49}In$	4.41×10^{14} yr

$T_{1/2}$; $\frac{R_0}{\lambda} = N_0$

$R = \lambda \cdot N$

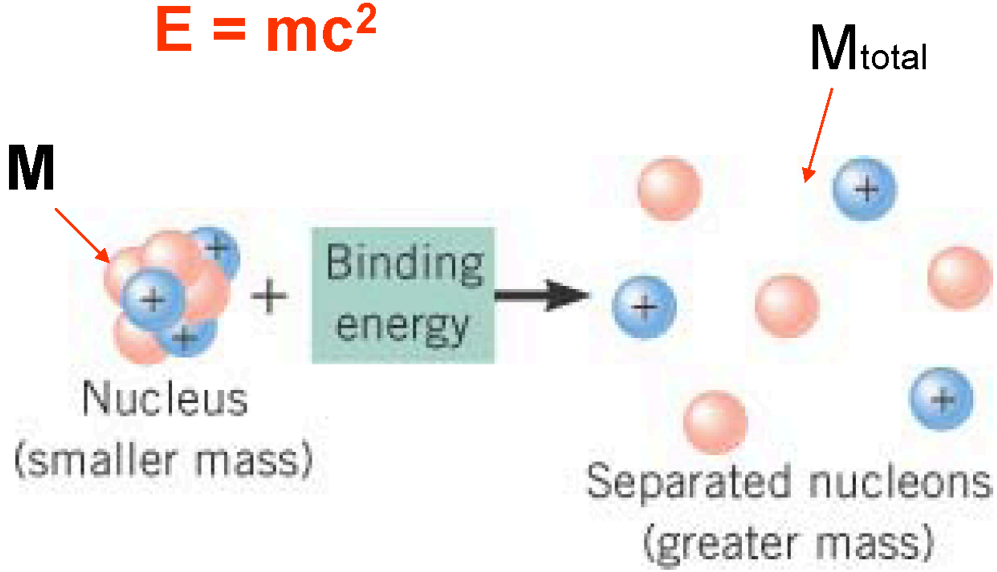


$\lambda = \frac{\ln 2}{T_{1/2}}$

$$N_1 = N_0 e^{-\lambda t} = \frac{N_0}{2^{n_1}}$$

$$N_2 = \frac{N_0}{2^{n_2}} \quad n_2 = \frac{t_2}{T_{1/2}} \qquad n_1 = \frac{t_1}{T_{1/2}}$$

$E = mc^2$

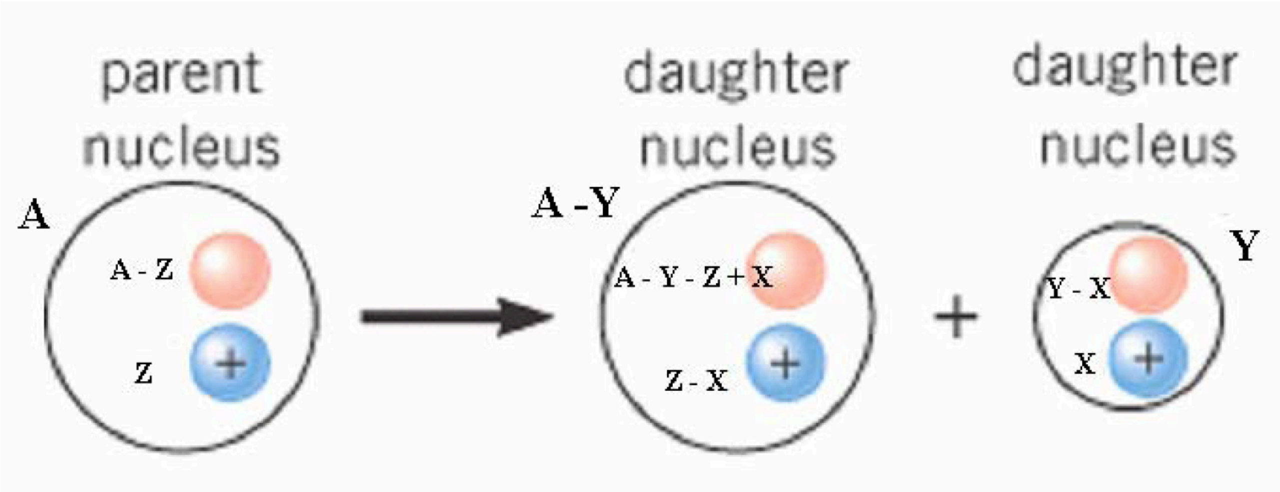


$$\text{Mass deficit} = \Delta m = M_{total} - M$$

$$\text{Binding energy} = (\text{Mass deficit})c^2 = (\Delta m)c^2$$

$$= (N_p * m_p + N_n * m_n + N_p * m_e - M_{atom}) * c^2$$

A Radioactive DECAY



$$^{A}_{Z}\mathrm{P} \rightarrow {}^{A-Y}_{Z-X}\mathrm{D}_1 + {}^{Y}_{X}\mathrm{D}_2$$

Do not forget about kinetic energy!

The total charge stays the same!

The total mass (energy) stays the same!

No matter how many parent nuclei are!