

Grade 12 ADV Physics EOT3 Sample Questions



تم تحميل هذا الملف من موقع المناهج الإماراتية

موقع المناهج ← المناهج الإماراتية ← الصف الثاني عشر المتقدم ← فيزياء ← الفصل الثالث ← ملفات متنوعة ← الملف

تاريخ إضافة الملف على موقع المناهج: 07:04:02 2026-06-11

ملفات اكتب للمعلم اكتب للطالب | اختبارات الكترونية | اختبارات | حلول | عروض بوربوينت | أوراق عمل
منهج انجليزي | ملخصات وتقارير | مذكرات وبنوك | الامتحان النهائي | للمدرس

المزيد من مادة
فيزياء:

إعداد: Jarwan Mutasem.T

التواصل الاجتماعي حسب الصف الثاني عشر المتقدم



صفحة المناهج
الإماراتية على
فيسبوك

الرياضيات

اللغة الانجليزية

اللغة العربية

التربية الاسلامية

المواد على تلغرام

المزيد من الملفات بحسب الصف الثاني عشر المتقدم والمادة فيزياء في الفصل الثالث

تجميعه هيكل الفيزياء انسباير بدون حل

1

بريديج أهم وحدات القياس والتحويلات في هيكل الوحدة 6 و 7

2

أهم وحدات القياس والتحويلات في هيكل الوحدة 6 و 7

3

أهم وحدات القياس والتحويلات في هيكل الفيزياء - بريديج

4

مراجعة الهيكل الوزاري لمادة الفيزياء

5

Grade 12 ADV Physics

UNITED ARAB EMIRATES
MINISTRY OF EDUCATION



الإمارات العربية المتحدة
وزارة التربية والتعليم

EOT3 Sample Questions

2025/2026 Exam coverage



T. Mutasem Jarwan





LO:

1

Explain Planck's concept of quantization of energy Calculate the energy emitted or absorbed by a vibrating atom in a solid using the equation

$$E = nhf$$



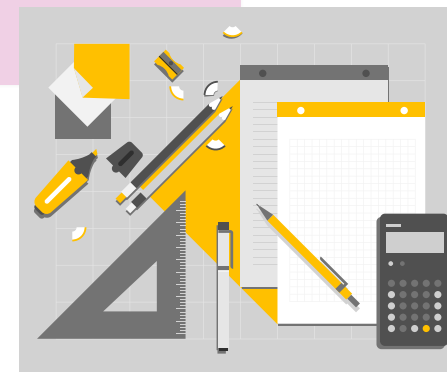
Example
/
Exercise

St. textbook

Practice problems

P- 68

P- 72



Emission Spectra explanation:



In 1900, German physicist **Max Planck** found that he could calculate the correct spectrum if an atom could only emit or absorb **particular amounts of energy**.

Planck hypothesized an **atom's energy changes** in a solid were proportional to a **frequency of vibration** times an integer.

ENERGY OF VIBRATION

The energy emitted or absorbed by a vibrating atom is equal to the product of an integer, Planck's constant, and the frequency of vibration.

$$E = nhf$$

f : frequency of vibration

h : Planck's constant = $6.62 \times 10^{-34} \text{ J/hz}$

n : an integer (0, 1, 2, 3 . . .)

The energy of the radiation (E) can have values of hf , $2hf$, $3hf$, and so on, but it can never have fractional values such as $2/3 hf$ or $3/4 hf$.

In other words, energy is **quantized**—it exists only in bundles of specific amounts.



Changes in vibrations:



Max Planck proposal:

Atoms emit radiation only at the **particular moments** when their vibrational energy changes.

- If the energy of an atom changes from:

$$3hf \rightarrow 2hf$$

The energy radiated is equal to the change in energy of the atom

$$\Delta E = 3hf - 2hf = hf$$

Similarly, if the atom absorbed energy

$$hf$$

its energy could change from

$$3hf \rightarrow 2hf$$



Why We Don't Notice This in Daily Life?

Planck found that because the **constant** (h) has an extremely small value, the **energy-changing steps** are very small.

- In everyday objects, energy changes appear continuous.

- But at the atomic level, energy actually changes in small discrete steps.



**PRACTICE PROBLEMS** (page 72)

1. What is a photon's energy if the photon's wavelength is 515 nm?

$$E = \frac{(1240 \text{ eV} \cdot \text{nm})}{\lambda}$$

$$E = hf$$

$$E = hf = hc \frac{1}{\lambda}$$

$$E = \frac{(1240 \text{ eV} \cdot \text{nm})}{515 \text{ nm}} = 2.4 \text{ eV}$$

$$E = \frac{(6.63 \times 10^{-34})(3 \times 10^8)}{(515 \times 10^{-9})}$$

$$E = 3.86 \times 10^{-19} \text{ J}$$

$$E = \frac{3.86 \times 10^{-19} \text{ J}}{1.6 \times 10^{-19} \text{ J/eV}} = 2.4 \text{ eV}$$

2. A photon's energy is 2.03 eV. What is the photon's wavelength?

$$E = \frac{(1240 \text{ eV} \cdot \text{nm})}{\lambda}$$

$$\lambda = \frac{(1240 \text{ eV} \cdot \text{nm})}{E}$$

$$\lambda = \frac{(1240 \text{ eV} \cdot \text{nm})}{2.03 \text{ eV}} = 610.8 \text{ nm}$$



**PRACTICE PROBLEMS** (page 72)

3. Rank the following photons from least to greatest energy.

A. 4.0 eV

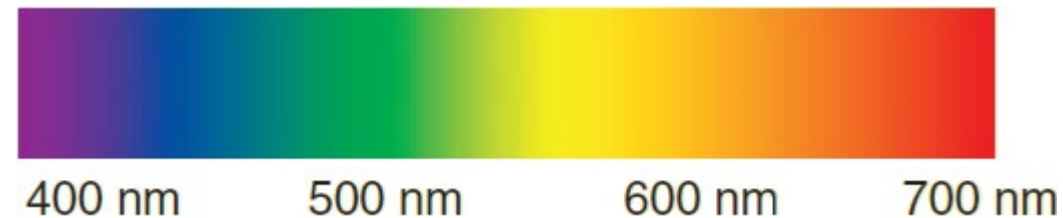
B. 320 nm $E = \frac{(1240 \text{ eV} \cdot \text{nm})}{320 \text{ nm}} = 3.87 \text{ eV}$

C. 811 nm $E = \frac{(1240 \text{ eV} \cdot \text{nm})}{811 \text{ nm}} = 1.53 \text{ eV}$

D. 2.1 eV

$$C < D < B < A$$

4. **CHALLENGE** The diagram in **Figure 6** shows the visible light spectrum. What is the range of energies associated with photons in the visible light spectrum?



$$E = \frac{(1240 \text{ eV} \cdot \text{nm})}{400 \text{ nm}} = 3.1 \text{ eV}$$

$$E = \frac{(1240 \text{ eV} \cdot \text{nm})}{700 \text{ nm}} = 1.77 \text{ eV}$$





Extra questions

14. According to Planck's theory, what is the frequency of vibration of an atom if it gives off $5.44 \times 10^{-19} J$ while changing its value of n by 1?

$$E = nhf$$

$$f = \frac{E}{nh}$$

$$f = \frac{5.44 \times 10^{-19}}{(1)(6.63 \times 10^{-34})} = 8.21 \times 10^{14} Hz$$





Extra questions

1. Which phenomenon could **NOT** be explained by classical electromagnetic wave theory?

- A- Reflection of light
- B- Emission spectrum**
- C- Diffraction of light
- D- Polarization of light

2. As the temperature of an object increases, the frequency at which maximum energy is emitted:

- A- Decreases
- B- Stay constant
- C- Increases**
- D- Becomes zero

3. According to Planck's theory, atoms emit radiation:

- A- Continuously at all times
- B- Only when their energy changes**
- C- Only at very high temperatures
- D- Only in visible light

4. If frequency doubles, the photon energy will:

- A- remain constant
- B- Double**
- C- Decrease
- D- become zero





Extra questions

5. The frequency of light beam A is twice that of light beam B. The ratio $\left(\frac{E_A}{E_B}\right)$ of photon energies is:

A- 1/2

B- 1/4

C- 2

D- 4

$$\frac{E_A}{E_B} = \frac{hf_A}{hf_B}$$

$$\frac{E_A}{E_B} = \frac{2f_B}{f_B}$$

$$\frac{E_A}{E_B} = 2$$

6. The wavelength of light beam A is twice the wavelength of light beam B. The energy of a photon in beam A is:

A- half the energy of a photon in beam B

B- one-fourth the energy of a photon in beam B

C- twice the energy of a photon in beam B

D- four times the energy of a photon in beam B

$$\frac{E_A}{E_B} = \frac{hf_A}{hf_B}$$

$$\frac{E_A}{E_B} = \frac{C/\lambda_A}{C/\lambda_B}$$

$$\frac{E_A}{E_B} = \frac{\lambda_B}{\lambda_A}$$

$$\frac{E_A}{E_B} = \frac{\lambda_B}{2\lambda_B}$$

$$\frac{E_A}{E_B} = \frac{1}{2}$$





Extra questions

9. The energy level of an atom changes when it absorbs and emits energy. Which of the following options **cannot** represent the energy level of an atom?

A- $3hf$

B- $2hf$

C- hf

D- $2/3hf$

11. What quantity is quantized in Max Planck's interpretation of the radiation emitted by objects?

The vibrational energy of the incandescent atoms is quantized.

12. Describe the concept of quantized energy.

Quantized energy means that energy can exist only in multiples of some minimum value.





LO:

2

Define the photoelectric effect.

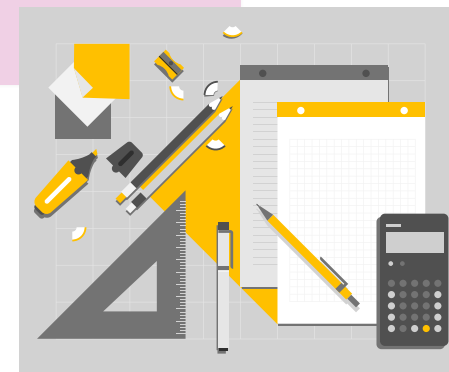
Explain how the photoelectric effect occurs when light shines on a metal surface.



Example
/
Exercise

St. textbook

P- 69



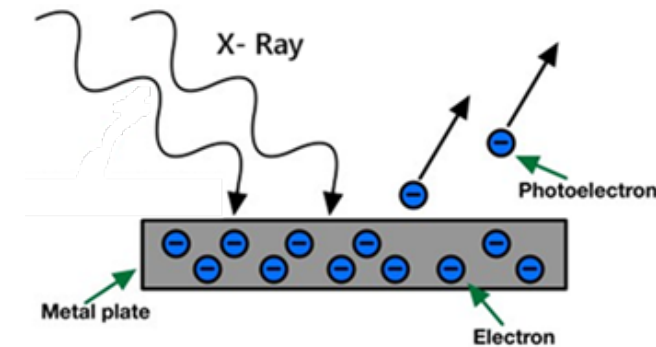
The Photoelectric effect:

Photoelectric effect: The emission of electrons when electromagnetic radiation falls on an object.



Electromagnetic wave theory predictions:

- The electric field in the light wave accelerates and ejects the electrons from the metal.
- The strength and energy of the electric field are related to the intensity of the light (not to its frequency).
- Electrons in the metal could absorb energy from a low-intensity, low-frequency light source for a **long time** and eventually gain enough energy to be ejected.



Electromagnetic wave theory, predicts the plate would emit electrons when any frequency of electromagnetic radiation shines on the plate.



Doesn't agree with experimental results.

FAIL

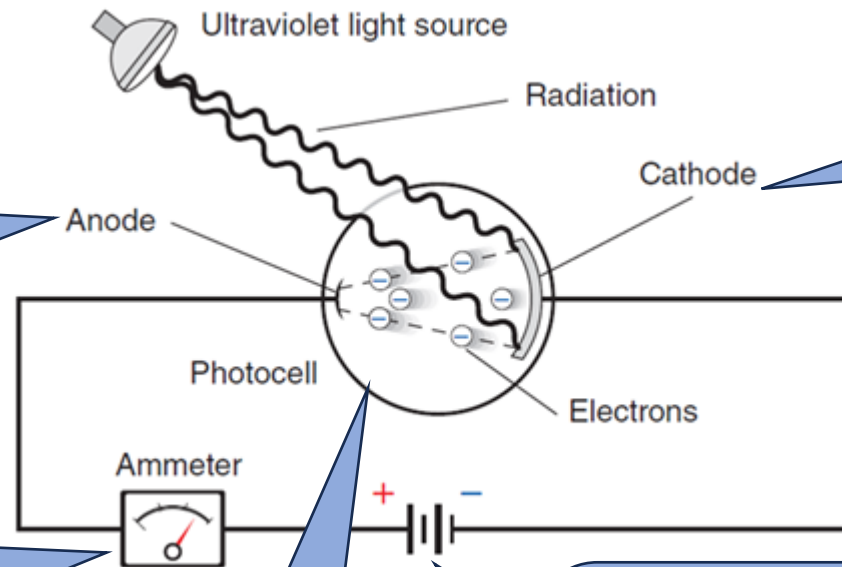
The photocell:

The photoelectric effect can be studied in a photocell, shown in the Figure.

The smaller electrode, called the **anode**, is made of a thin wire so that it blocks only a very small amount of radiation.

When light with certain frequencies falls on the cathode, a **current** is produced, which is measured by the ammeter

A transparent **tube** allows ultraviolet light to pass through it.

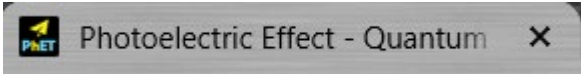


The larger electrode, called the **cathode**, usually is coated with cesium or another alkali metal.

- Electrons in the cathode absorb the energy from the light.
- The electrons escape the potential energy that holds them in the cathode and travel to the anode, which is the positive electrode.
- This flow of photoelectrons forms the current in the circuit.

A **potential difference** placed across the electrodes attracts electrons ejected from the cathode to the anode.

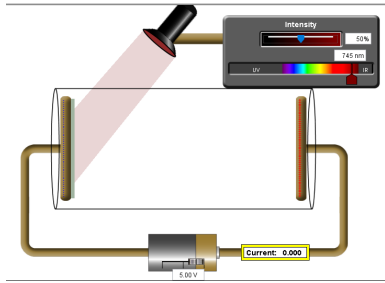
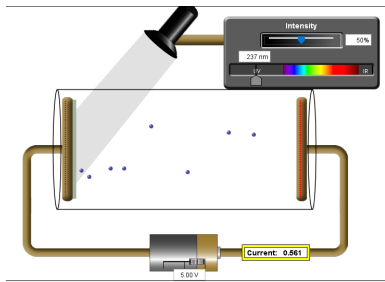
The photocell:



<https://phet.colorado.edu/en/simulations/photoelectric>



Does any type of light can eject electrons?

Using red light 50% intensity	No Electrons ejected	
Using UV light 50% intensity	Electrons ejected	



Conclusion:

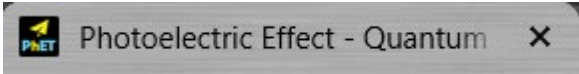
Electrons can't be ejected using any type of light.

the frequency of the light should be greater than a certain minimum value

Threshold frequency (f_0)



The photocell:



<https://phet.colorado.edu/en/simulations/photoelectric>



Does changing the intensity of the light can eject electrons?



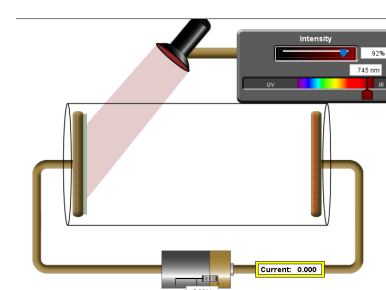
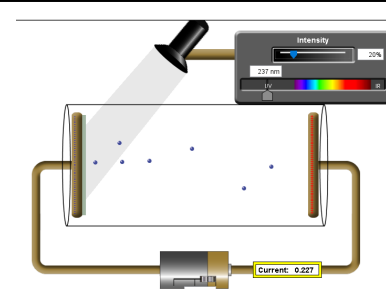
Conclusion:

increasing the intensity of the **red** light didn't eject any electrons.

For the **UV** light:

Increasing the intensity of the light increased the current (number of electrons)

Decreasing the intensity decrease the current (number of electrons)

Using red light 90% intensity	No Electrons ejected	
Using UV light 20% intensity	Electrons ejected The current decrease (number of electrons decrease)	



Check Your Progress (page 78)

16. Photovoltaic Materials Why is high-intensity, low-frequency light unable to eject electrons from a metal, whereas low-intensity, high-frequency light can?

Each incident photon interacts with a single electron. If the incident photon does not have sufficient energy, it cannot eject an electron.

Because energy is directly related to frequency, low-frequency light does not have sufficient energy to eject an electron, whereas high-frequency light does.





Extra questions

12. The emission of electrons from the surface of a metal when illuminated by a specific light depends on:

A- angle of incidence

B- the wavelength

C- the intensity

D- the speed of light





LO:

3

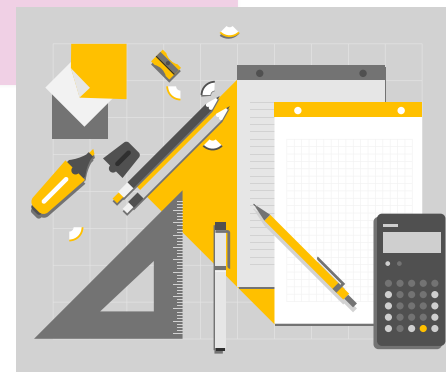
Explain that electrons are ejected from the surface of a metal only if the frequency of the radiation is greater than a threshold frequency



Example
/
Exercise

St. textbook

P- 70





LO:

5

Explain that the maximum kinetic energy of photoelectrons is independent of the intensity of incident electromagnetic radiation.

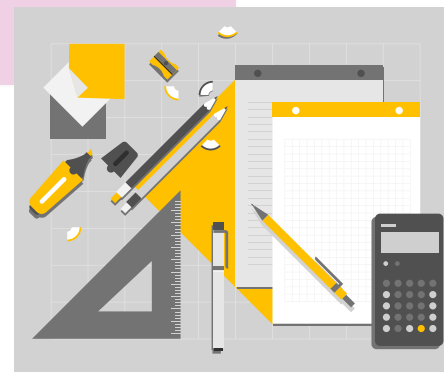
Explain that the current due to photoelectrons (photoelectric current) is proportional to the intensity of incident electromagnetic radiation



Example
/
Exercise

St. textbook

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Threshold frequency and intensity of the light:



Threshold frequency (f_0): the minimum frequency of incident radiation that can eject Electrons from the metal without having a kinetic energy.



Why electromagnetic wave theory failed to explain the photoelectric effect?

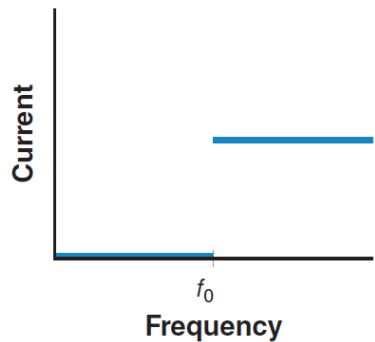
Any frequency of electromagnetic radiation should eject electrons from the metal.

Experimental result:

The graph shows that there is a current only when the threshold frequency is reached.

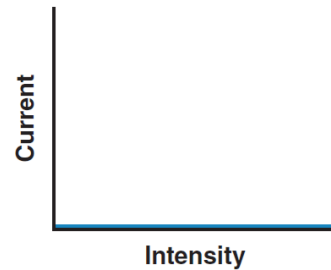
The value of the threshold frequency varies widely and depends on the type of metal used for the cathode.

Constant Intensity



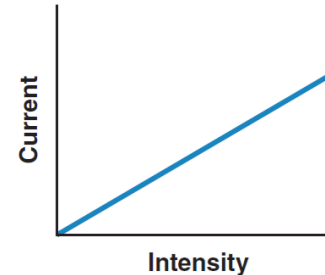
even very low-intensity radiation with a frequency at or above f_0 causes the immediate emission of electrons from the cathode

Constant Frequency < Threshold Frequency



even intense radiation with a frequency below f_0 will not cause the emission of electrons.

Constant Frequency $\geq$ Threshold Frequency



When incoming radiation, has a frequency equal to or greater than the threshold frequency, increasing the intensity of the radiation increases the current through the photocell.

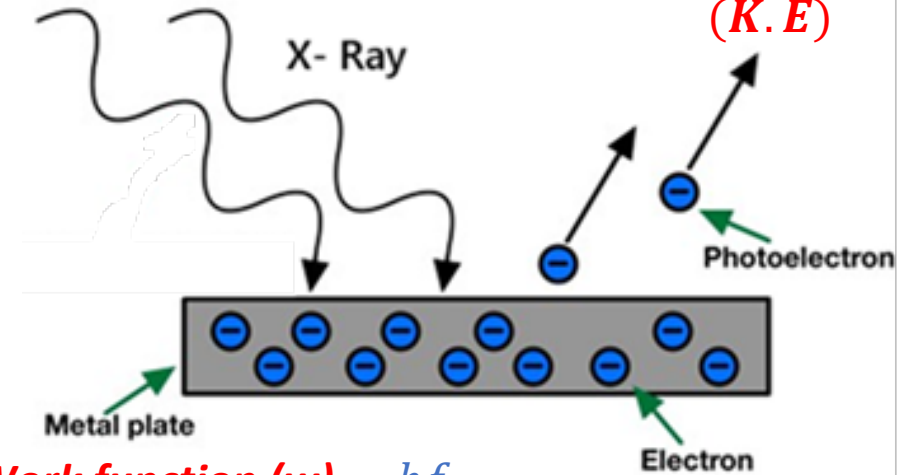
Kinetic Energy Of Ejected Electrons:

$f < f_0$	Photon energy Less than work function	No electrons ejected
$f = f_0$	Photon energy equals work function	Electrons ejected with no K.E
$f > f_0$	Photon energy grater than work function	Electrons ejected with K.E

The kinetic energy of an ejected electron is equal to the difference between the incident photon energy (hf) and the energy of a photon with the threshold frequency (hf_0).

Photon energy = hf

Electron with (K.E)



Work function (w) = hf_0

$$K.E = E_{\text{photon}} - W$$

$$K.E = hf - hf_0$$



Extra questions

2. Light above the threshold frequency shines on the cathode in a photocell. How does Einstein's photoelectric effect theory explain the fact that as the light intensity increases, photoelectron current increases?

Each photon ejects a photoelectron.

Light with greater intensity contains more photons per second; thus, it causes the ejection of more photoelectrons per second.

3. Describe how Einstein's photon theory accounts for the fact that light below the threshold frequency of a metal produces no photoelectrons, regardless of the intensity of the light.

Photons below the threshold frequency do not have sufficient energy to eject an electron.

If the intensity of the light increases, the number of photons increases but their energy does not; the photons are still unable to eject an electron.



Extra questions

8. Light falls on the surface of a metal and causes photoelectric emission. What happens to the **number of electrons** emitted from the metal surface and the **maximum kinetic energy** of the emitted electrons when the **intensity** of the light increases?

	The number of electrons	Maximum kinetic energy of emitted electrons
A	Decreases	Does not change
B	Increases	Does not change
C	Does not change	Decreases
D	Does not change	Increases

9. Light falls on the surface of a metal and causes photoelectric emission. What happens to the **number of photons** incident on the metal surface and the **maximum kinetic energy** of the emitted electrons when the **frequency** of the light increases?

	Number of incident photons	Maximum kinetic energy of emitted electrons
A	Decreases	Does not change
B	Increases	Does not change
C	Does not change	Decreases
D	Does not change	Increases



Extra questions

12. The emission of electrons from the surface of a metal when illuminated by a specific light depends on:

A- angle of incidence

B- the wavelength

C- the intensity

D- the speed of light

15. When a light falls on the surface of potassium and photoelectrons are emitted from it, the number of electrons emitted from the potassium surface is directly proportional to:

A- the intensity of the incident light

B- the frequency of the incident light

C- the work function

D- the threshold frequency





Extra questions

21. How is the threshold frequency related to the photoelectric effect?

- A.** It is the minimum frequency of incident radiation needed to cause the ejection of atoms from the anode of a photocell.
- B.** It is the maximum frequency of incident radiation needed to cause the ejection of atoms from the anode of a photocell.
- C.** It is the frequency of incident radiation below which electrons will be ejected from an atom.
- D.** It is the minimum frequency of incident radiation needed to cause the ejection of electrons from an atom.

28. Will high-frequency light eject a greater number of electrons from a photosensitive surface than low-frequency light, assuming that both frequencies are above the threshold frequency?

Not necessarily; the number of ejected electrons is proportional to the number of incident photons or the brightness of the light, not the frequency of the light.





Get It?

Explain how an electron emitted by the photoelectric effect can have kinetic energy less than the threshold energy.

The kinetic energy is the difference between the photon energy hf and the threshold energy hf_0 .

If the photon energy is just slightly larger than the threshold energy, this difference (i.e., the kinetic energy) will be smaller than the threshold energy.





LO:

4

Calculate the energy of a photon given its wavelength or frequency.

Calculate the maximum kinetic energy of an electron ejected due to the photoelectric effect



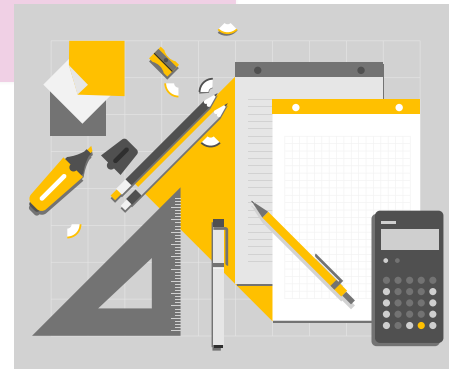
Example
/
Exercise

Example problem 1,2

Practice problems

P- 74

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Blank And Einstein:



- Einstein's photon theory explains the **existence of a threshold frequency** and the prompt emission of electrons during the photoelectric effect.
- A photon with a minimum frequency (f_0) will have minimum energy (hf_0) that can eject an electron from metal without having any K.E.

$$\text{Work function (w)} = hf_0$$

- If the photon frequency is less than f_0 , the photon will not have the energy needed to pry the electron from the metal.

(Because one photon interacts with one electron, an electron cannot simply store energy from low frequency photons until it collects enough energy to break free.)

- On the other hand, radiation with a frequency greater than f_0 provides more than enough energy to eject an electron. In fact, the excess energy, $hf - hf_0$, becomes the ejected **electron's kinetic energy**.



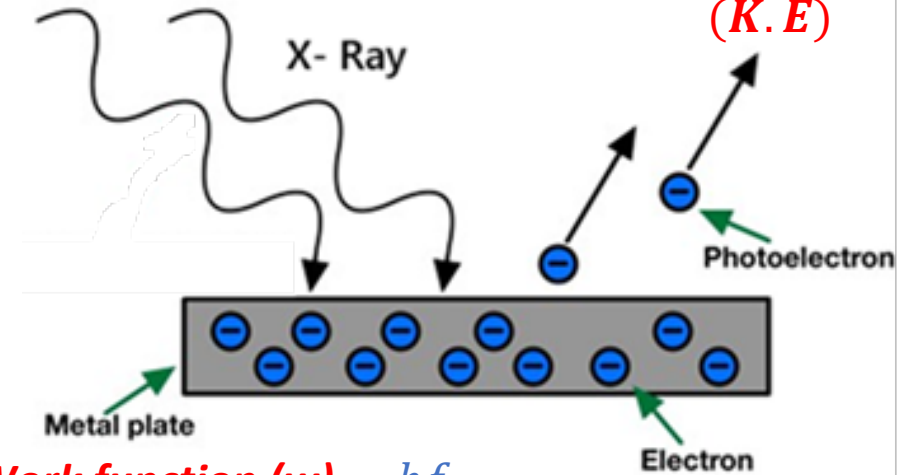
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The kinetic energy of an ejected electron is equal to the difference between the incident photon energy (hf) and the energy of a photon with the threshold frequency (hf_0).

Photon energy = hf

Electron with (K.E)



Work function (w) = hf_0

$$K.E = E_{\text{photon}} - W$$

$$K.E = hf - hf_0$$



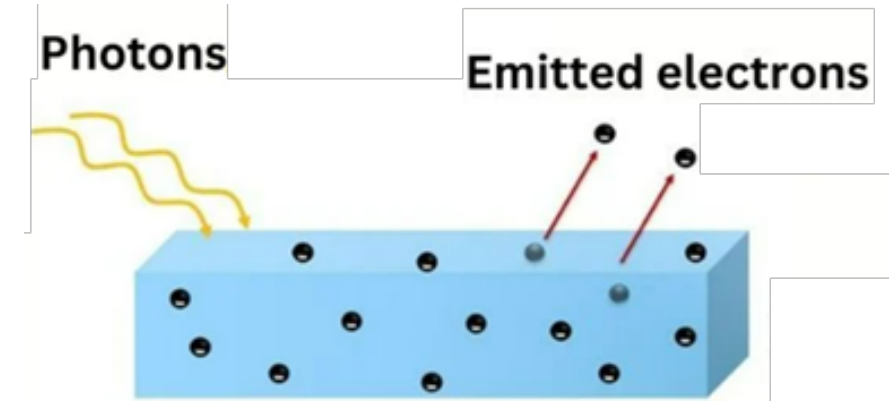
Kinetic Energy Of Ejected Electrons:



When electrons ejected from a metal does all of them have the same K.E?

Not all electrons in a metal have the same energy; some will require more energy in order to escape (location of the electron).

Electrons are not just on the surface; many are deeper inside the metal. While escaping, these deeper electrons collide with other atoms and lose some of their energy as heat



As a result, the ejected electrons have differing kinetic energies.

Thus, it is important to realize that the phrase “**kinetic energy of the ejected electrons**” refers to the **maximum kinetic energy** that an ejected electron could have. Some of the ejected electrons will have less.





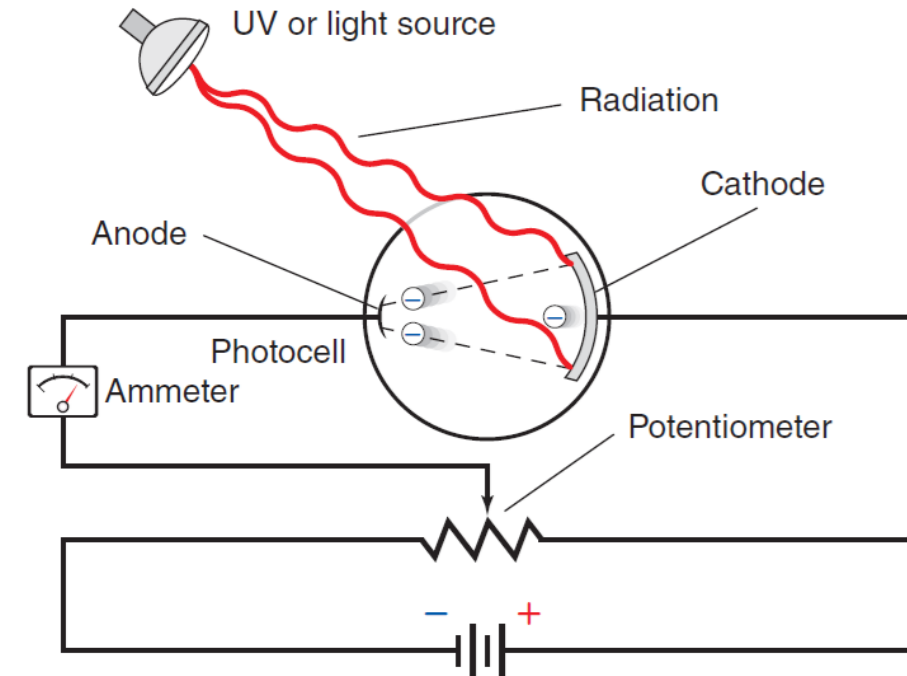
Testing the photon theory:

- At the stopping potential, the electrons' kinetic energy at the cathode equals the work done by the electric field to stop them.

$$K.E_{max} = -e\Delta V_o$$

ΔV_o : The stopping potential difference (V)

e : The charge of the electron ($-1.602 \times 10^{-19}C$).



Calculations of electrons' kinetic energy based on this experiment support Einstein's photon theory.



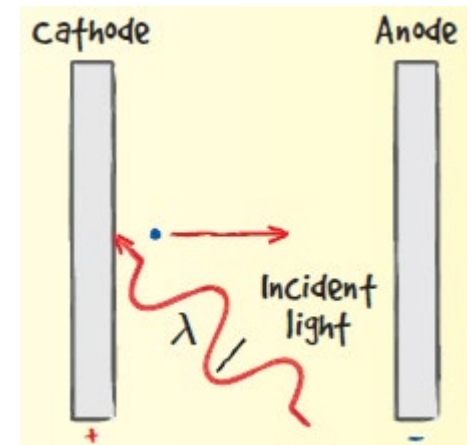
**EXAMPLE PROBLEM 1** (page 74)

PHOTOELECTRON KINETIC ENERGY The stopping potential difference of a certain photocell is **4.0 V**. How much kinetic energy does the incident light give the electrons? Give your answer in both joules and electron volts.

$$K.E = -e\Delta V_o$$

$$K.E = -(-1.602 \times 10^{-19})(4) = 6.4 \times 10^{-19} J$$

$$K.E = (6.4 \times 10^{-19} J) \left(\frac{1 eV}{1.602 \times 10^{-19}} \right) = 4 eV$$



EXAMPLE PROBLEM 2 (page 76)

WORK FUNCTION AND ENERGY A particular photocell uses a sodium cathode. Sodium has a threshold wavelength of **526 nm**.

a. Find the work function of sodium in **eV**.

$$W = hf_o$$

$$W = h \frac{c}{\lambda_o}$$

$$W = \frac{(1240 \text{ eV} \cdot \text{nm})}{(526 \text{ nm})} = 2.36 \text{ eV}$$

b. If ultraviolet radiation with a wavelength of **348 nm** falls on sodium, will the cathode discharge electrons? If so, what is the maximum energy of the ejected electrons in **eV**?

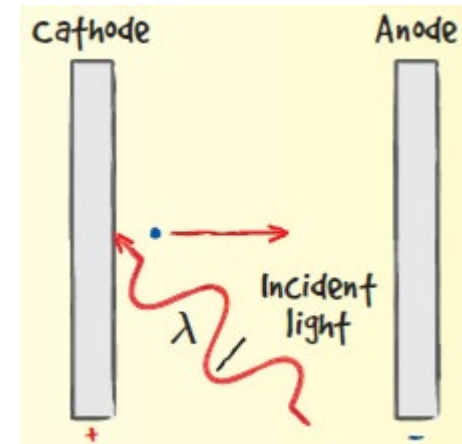
$$E = h \frac{c}{\lambda_o}$$

$$E = \frac{(1240 \text{ eV} \cdot \text{nm})}{(348 \text{ nm})} = 3.56 \text{ eV}$$

$$K.E = h \frac{c}{\lambda} - h \frac{c}{\lambda_o}$$

$$K.E = 3.56 - 2.36 = 1.2 \text{ eV}$$

The cathode will discharge electrons ($E > W$)



**PRACTICE PROBLEMS** (page 76)

12. The threshold **wavelength** of zinc is **310 nm**. Find the threshold frequency, in **Hz**, and the work function, in **eV**, of zinc.

$$f_o = \frac{c}{\lambda_o} = \frac{3 \times 10^8}{310 \times 10^{-9}} = 9.67 \times 10^{14} \text{ Hz}$$

$$W = hf_o$$

$$W = h \frac{c}{\lambda_o}$$

$$W = \frac{(1240 \text{ eV} \cdot \text{nm})}{(310 \text{ nm})} = 4 \text{ eV}$$

13. The work function for cesium is **1.95 eV**. What is the maximum kinetic energy, in **eV**, of photoelectrons ejected when **425 nm** violet light falls on the cesium?

$$K.E = h \frac{c}{\lambda} - h \frac{c}{\lambda_o}$$

Work function (W)

$$K.E = \frac{(1240 \text{ eV} \cdot \text{nm})}{(425 \text{ nm})} - 1.95 = 0.967 \text{ eV}$$



**PRACTICE PROBLEMS** (page 76)

14. When a metal is illuminated with 193 nm ultraviolet radiation, electrons with kinetic energies of 3.5 eV are emitted. What is the work function of the metal?

$$K.E = h \frac{c}{\lambda} - W$$

$$W = K.E - h \frac{c}{\lambda}$$

$$W = 3.5 - \frac{(1240 \text{ eV} \cdot \text{nm})}{(193 \text{ nm})} = 2.92 \text{ eV}$$

15. **CHALLENGE** A researcher illuminates a sample of metal and finds the longest wavelength to eject electrons is 273 nm. Use **Table 1** to identify the most likely metal.

$$W = hf_o$$

$$W = h \frac{c}{\lambda_o}$$

$$W = \frac{(1240 \text{ eV} \cdot \text{nm})}{(273 \text{ nm})} = 4.5 \text{ eV}$$

Table 1 Threshold Frequency, Threshold Wavelength, and Work Function for Selected Metals

Metal	Threshold Frequency ($\times 10^{14}$ Hz)	Threshold Wavelength (nm)	Work Function (eV)
Cesium	4.70	637	1.95
Magnesium	8.84	339	3.66
Silver	11.1	270	4.6
Sodium	5.70	526	2.36



**Extra questions**

6. What potential difference is needed to stop electrons with a maximum kinetic energy of $4.8 \times 10^{-19} J$?

$$K.E = -e\Delta V_o$$

$$\Delta V_o = \frac{K.E}{-e}$$

$$\Delta V_o = \frac{(4.8 \times 10^{-19})}{(-1.602 \times 10^{-19})} = 3 V$$

7. The threshold frequency of a certain metal is $3.00 \times 10^{14} Hz$. What is the maximum kinetic energy of an ejected photoelectron if the metal is illuminated by light with a wavelength of $6.50 \times 10^2 nm$?

$$K.E = h \left(\frac{c}{\lambda} - f_o \right)$$

$$K.E = (6.63 \times 10^{-34}) \left(\frac{3 \times 10^8}{6.5 \times 10^{-7}} - 3 \times 10^{14} \right)$$

$$K.E = 1.07 \times 10^{-19} J$$



**Extra questions**

22. A helium-neon laser emits photons with a wavelength of 632.8 nm . What is the energy, in joules, of each photon emitted by the laser?

A. $3.135 \times 10^{-19} J$

B. $8.231 \times 10^{-17} J$

C. $2.546 \times 10^8 J$

D. $1.639 \times 10^{34} J$

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

$$E = (6.62 \times 10^{-34}) \frac{3 \times 10^8}{632.8 \times 10^{-9}}$$

$$E = 3.138 \times 10^{-19} J$$

23. A photon has a frequency of $1.14 \times 10^{15} \text{ Hz}$. What is the energy of the photon?

A. $5.82 \times 10^{-49} J$

B. $7.55 \times 10^{-19} J$

C. $8.77 \times 10^{-19} J$

D. $1.09 \times 10^{-12} J$

$$E = hf$$

$$E = (6.62 \times 10^{-34})(1.14 \times 10^{15})$$

$$E = 7.55 \times 10^{-19} J$$





Extra questions

25. If light with a frequency of $1.00 \times 10^{15} \text{ Hz}$ falls on the sodium in the previous problem, what is the maximum kinetic energy of the photoelectrons?

$$K.E = hf - hf_o$$

$$K.E = h(f - f_o)$$

$$K.E = (6.63 \times 10^{-34})(1 \times 10^{15} - 4.4 \times 10^{14})$$

$$K.E = 3.7 \times 10^{-19} \text{ J}$$



Extra questions

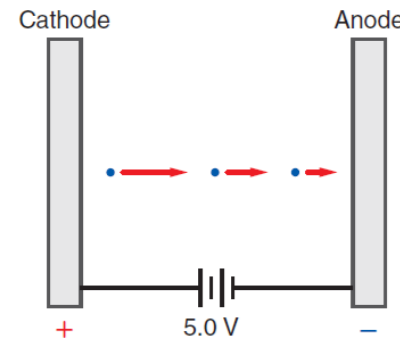
26. The stopping potential of a certain metal is shown in **Figure 14**. What is the maximum kinetic energy of the photoelectrons in the following units?

a. electron volts.

$$K.E = 5eV$$

b. joules.

$$K.E = (5eV) \left(\frac{1.602 \times 10^{-19}}{1eV} \right) = 8 \times 10^{-19} J$$



27. Light Meter A photographer's light meter uses a photocell to measure the light falling on the subject to be photographed. What should be the work function of the cathode if the photocell is to be sensitive to red light ($\lambda = 680 \text{ nm}$) as well as to the other colors of light?

$$W = hf_o$$

$$W = h \frac{c}{\lambda_o}$$

$$W = \frac{(1240eV \cdot nm)}{(680nm)} = 1.8 eV$$



Extra questions

32. The work function for a certain piece of iron is 4.7 eV.

a. What is the threshold wavelength of iron?

$$W = h \frac{c}{\lambda_o}$$

$$\lambda_o = h \frac{c}{W} = \frac{1240 \text{ eV} \cdot \text{nm}}{4.7 \text{ eV}} = 260 \text{ nm}$$

b. Iron is exposed to radiation of wavelength 150 nm. What is the maximum kinetic energy of the ejected electrons in eV?

$$K.E = h \frac{c}{\lambda} - W$$

$$K.E = \frac{1240 \text{ eV} \cdot \text{nm}}{150 \text{ nm}} - 4.7 = 3.6 \text{ eV}$$

35. Radiation with an energy of 5.17 eV strikes a photocell, as shown below. If the work function of the photocell is 2.31 eV, what is the energy of the ejected photoelectron?

A. 0.00 eV

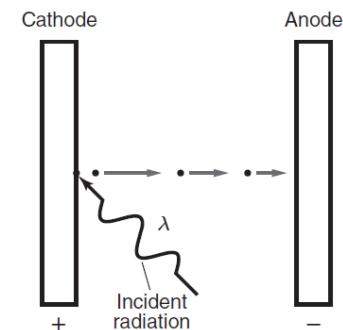
B. 2.23 eV

C. 2.86 eV

D. 7.48 eV

$$K.E = hf - hf_o$$

$$K.E = 5.71 - 2.31 = 2.86 \text{ eV}$$





LO:

6

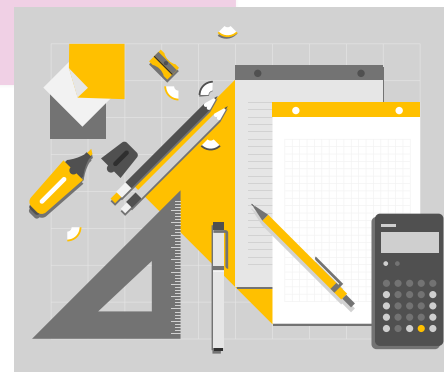
Interpret the graph of maximum kinetic energy of an electron ejected from a metal versus the frequency of incident photon and determine graphically the threshold frequency and Planck's constant.



Example
/
Exercise

St. textbook

P- 75



Work function:



All metals have similar graphs with the same slope.

This slope equal to Planck's constant (h).

- The graphs of various metals differ only in the threshold frequency needed to free the electrons.
- The threshold frequency (f_0) is the point at which $KE = 0$.
- f_0 is located at the intersection of the line with the x-axis.

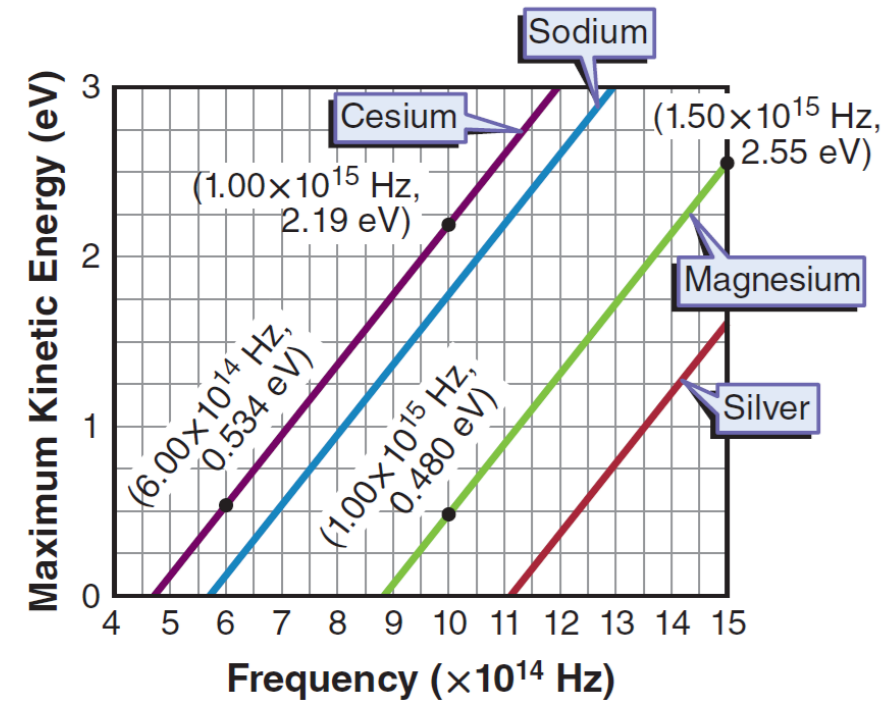


Work function The minimum energy of a photon that can eject an electron from the metal with no kinetic energy.

(the energy needed to free the most weakly bound electron from the metal).

$$\text{Work function } (w) = hf_0$$

Maximum Kinetic Energy v. Frequency



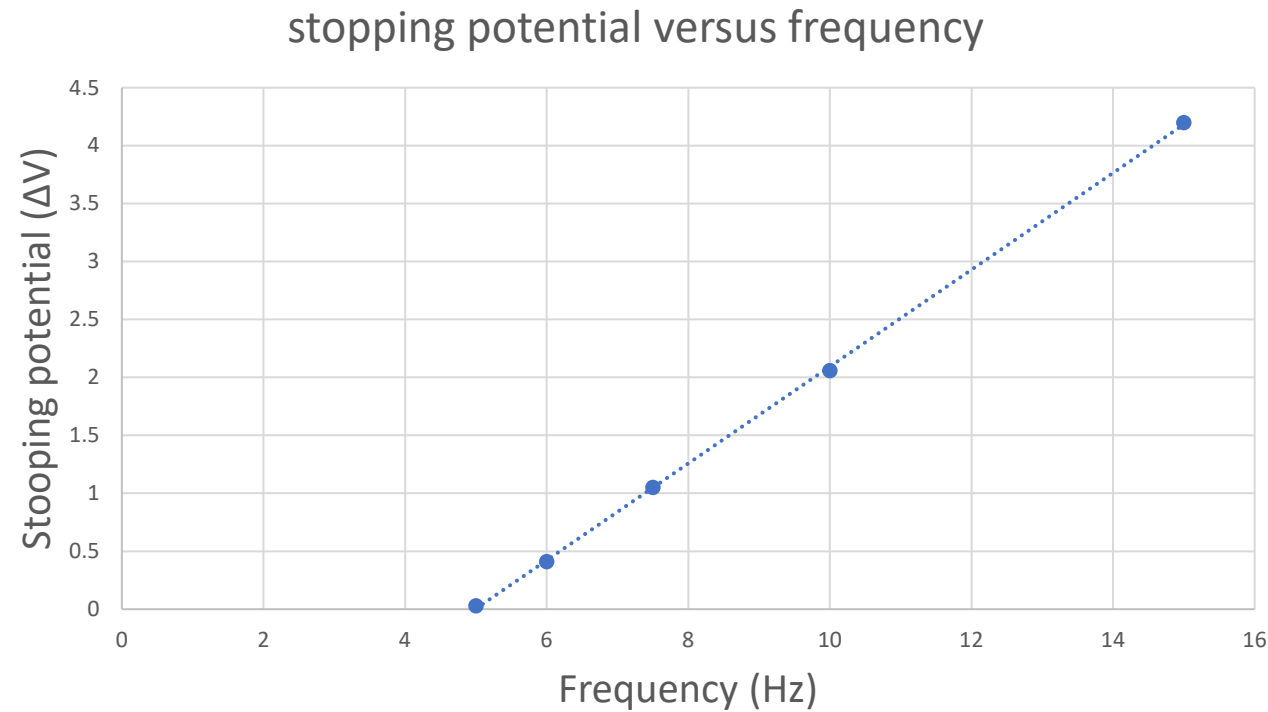
When a photon of frequency f_0 is incident on a metal, the energy of the photon is sufficient to release an electron but not sufficient to provide the electron with any kinetic energy.

Extra questions

4. Make and Use Graphs A student completed a photoelectric-effect experiment and recorded the stopping potential as a function of wavelength, as shown in **Table 2**. The photocell had a sodium cathode.

A- Plot the stopping potential versus frequency. Use your calculator to draw the best-fit straight line (regression line). ($f = C/\lambda$) and ($C = 3 \times 10^8 m/s$)

Wavelength $\lambda(\text{nm})$	Stopping potential $\Delta V_0(\text{V})$	Frequency (Hz)
200	4.20	15×10^{14}
300	2.06	10×10^{14}
400	1.05	7.5×10^{14}
500	0.41	6.0×10^{14}
600	0.03	5.0×10^{14}



Extra questions

B- From the slope and intercept of the line, find each of the following:

1- The work function:

$$W = hf_0$$

$$W = (6.63 \times 10^{-34})(5 \times 10^{14}) = 3.315 \times 10^{-19} J$$

2- The threshold wavelength:

$$\lambda_0 = \frac{c}{f_0} = \frac{3 \times 10^8}{5 \times 10^{14}} = 6 \times 10^{-7} m$$

3- The value of (h/e) from this experiment. Compare the value of (h/e) to the accepted value.

Experiment value

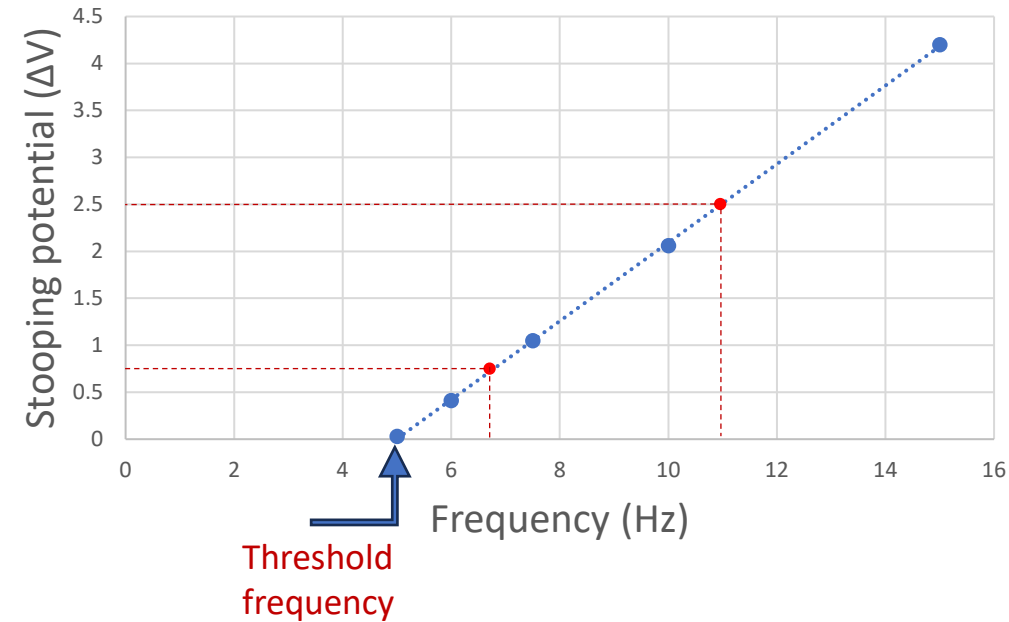
$$\frac{h}{e} = \text{slope} = \frac{2.5 - 0.75}{11 \times 10^{14} - 6.8 \times 10^{14}}$$

$$\frac{h}{e} = 4.166 \times 10^{-15} J/Hz.C$$

Accepted value

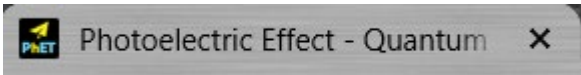
$$\frac{h}{e} = \frac{6.63 \times 10^{-34}}{1.60 \times 10^{-19}} = 4.14 \times 10^{-15} J/Hz.C$$

stopping potential versus frequency

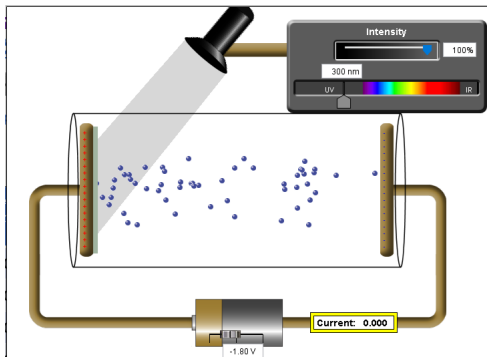




Testing the photon theory:



<https://phet.colorado.edu/en/simulations/photoelectric>



1- Open the simulation and chose (sodium) to be tested.

2- change the wavelength of light according to the table keeping the intensity of the light constant and fill in the table.

Wavelength $\lambda(\text{nm})$	Frequency (Hz)	Stopping potential $\Delta V_0(\text{V})$	$K.E_{\text{max}}$ (eV)
250	12×10^{14}	2.62	4.19×10^{-19}
300	10×10^{14}	1.79	2.86×10^{-19}
350	8.5×10^{14}	1.18	1.88×10^{-19}
400	7.5×10^{14}	0.72	1.15×10^{-19}
450	6.6×10^{14}	0.33	0.52×10^{-19}

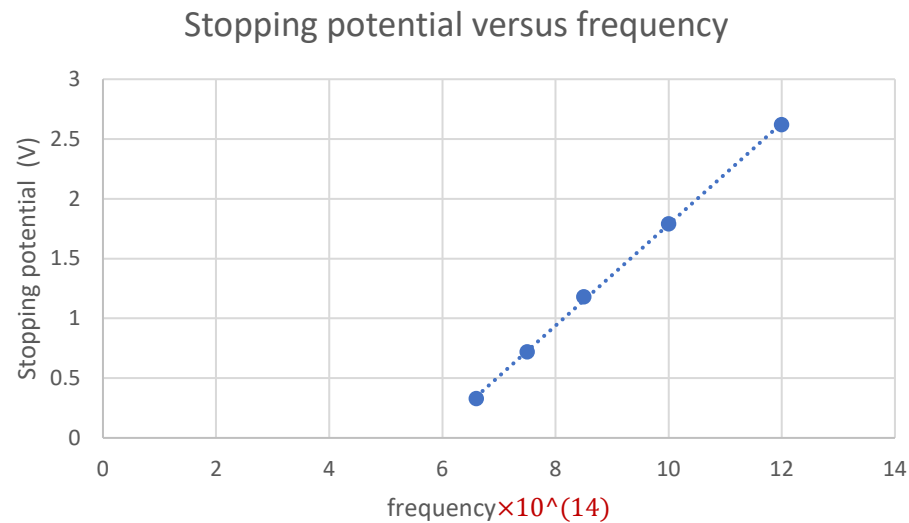
$$(f = C/\lambda) \text{ and } (C = 3 \times 10^8 \text{ m/s})$$



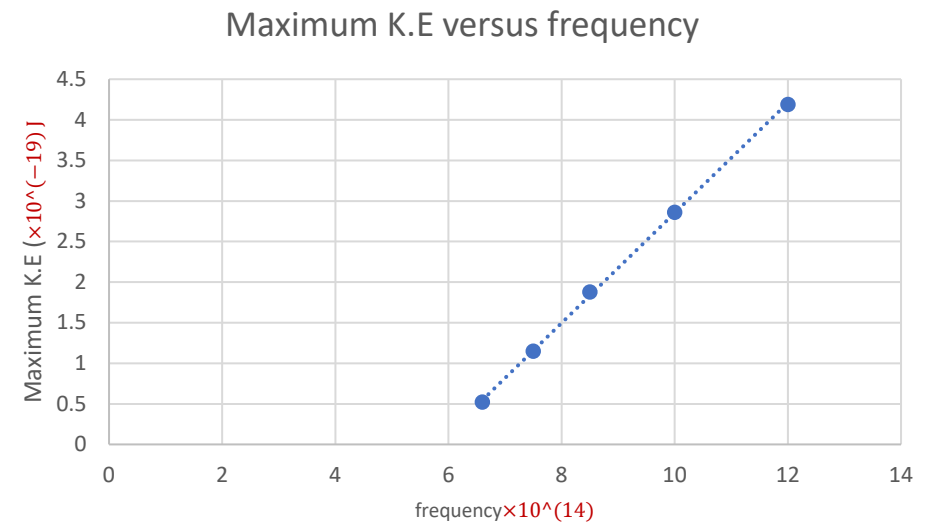


Testing the photon theory:

A- Plot the stopping potential versus frequency. draw the best-fit straight line (regression line).



B- Plot the Maximum K.E versus frequency. draw the best-fit straight line (regression line).



Testing the photon theory:

C- Calculate the slope of the line in graph 1.

Slope graph 1

$$\text{Slope} = \frac{(3.5 - 1.5) \times 10^{-19}}{(11 - 8) \times 10^{14}} = 6.66 \times 10^{-34}$$

Compare the slope with
the value of (h).
 $h = 6.63 \times 10^{-34}$

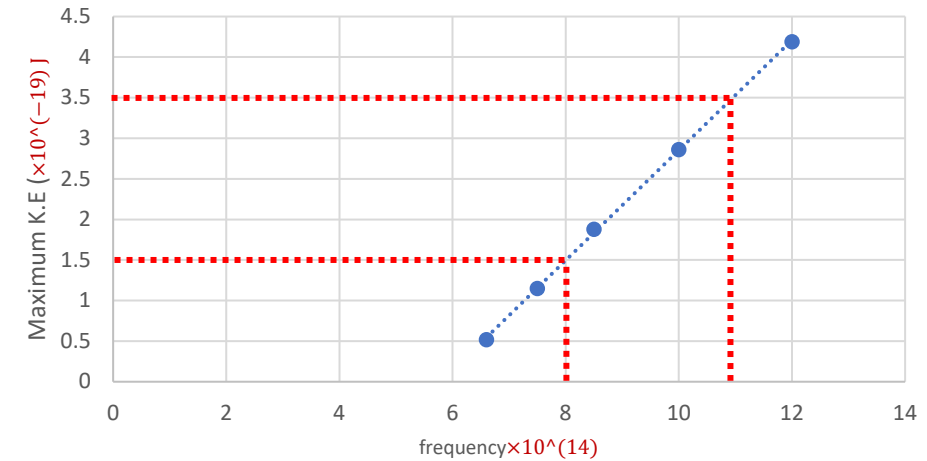
D- Calculate the slope of the line in graph 2.

Slope graph 2

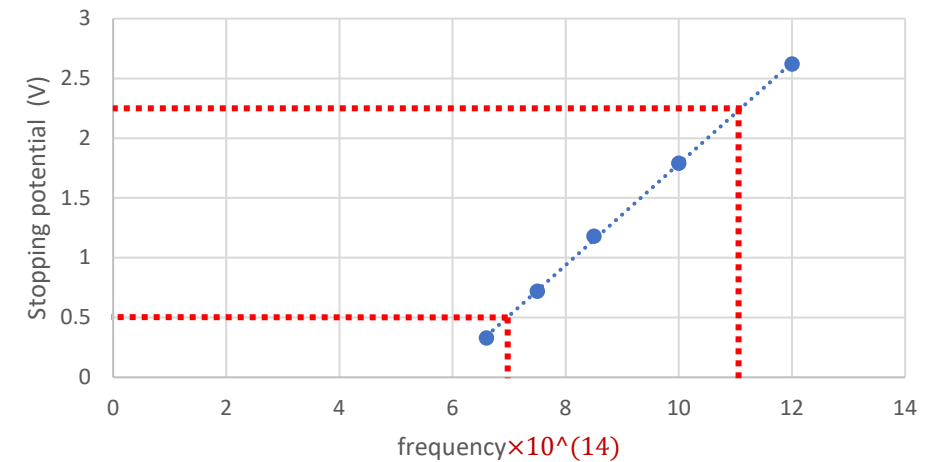
$$\text{Slope} = \frac{(2.25 - 0.5)}{(11 - 7) \times 10^{14}} = 4.375 \times 10^{-15}$$

Compare the slope with
the value of (h/e).
 $\frac{h}{e} = \frac{6.63 \times 10^{-34}}{1.60 \times 10^{-19}}$
 $\frac{h}{e} = 4.14 \times 10^{-15} \text{ J/Hz.C}$

Maximum K.E versus frequency



Stopping potential versus frequency



Testing the photon theory:

E- Using the graph calculate the work function:

Graph 1

$$W = E_{\text{Photon}} - K.E$$

$$W = hf - K.E$$

$$W = (6.63 \times 10^{-34})(8 \times 10^{14}) - (1.5 \times 10^{-19}) = 3.78 \times 10^{-19}J$$

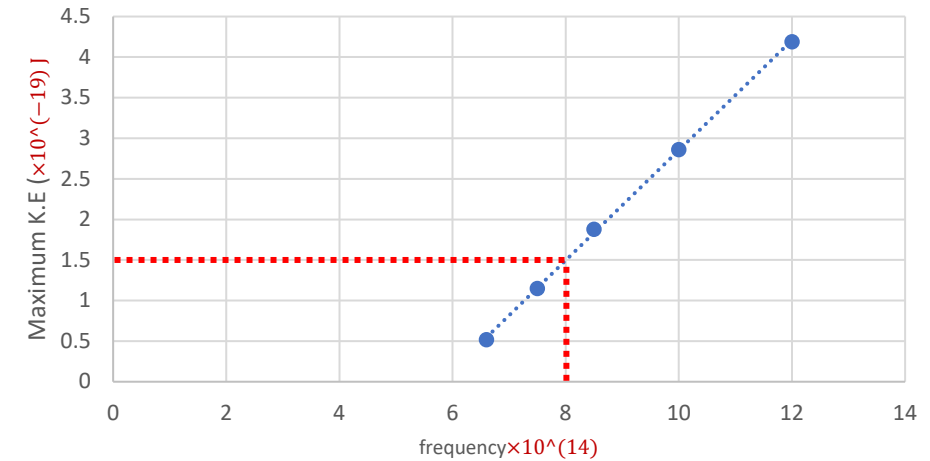
Graph 2

$$W = E_{\text{Photon}} - K.E$$

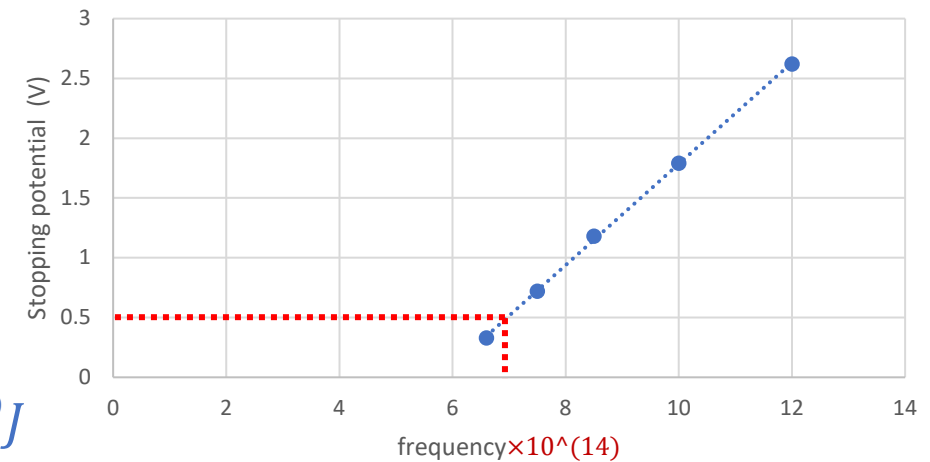
$$W = hf - (-e\Delta V)$$

$$W = (6.63 \times 10^{-34})(7 \times 10^{14}) - (1.6 \times 10^{-19})(0.5) = 3.84 \times 10^{-19}J$$

Maximum K.E versus frequency



Stopping potential versus frequency



Testing the photon theory:

F- Using the work function that you calculated find the threshold frequency:

Graph 1

$$W = hf_0$$

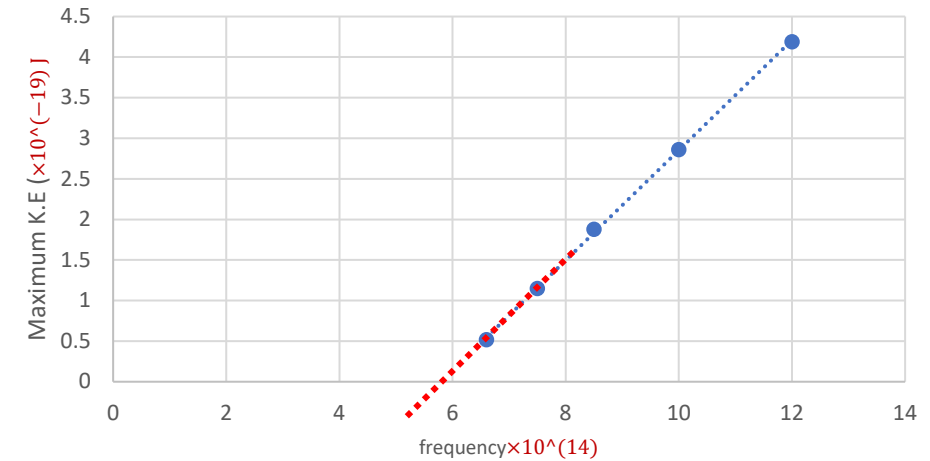
$$f_0 = \frac{W}{h} = \frac{3.78 \times 10^{-19}}{6.63 \times 10^{-34}} = 5.70 \times 10^{14} \text{ Hz}$$

Graph 2

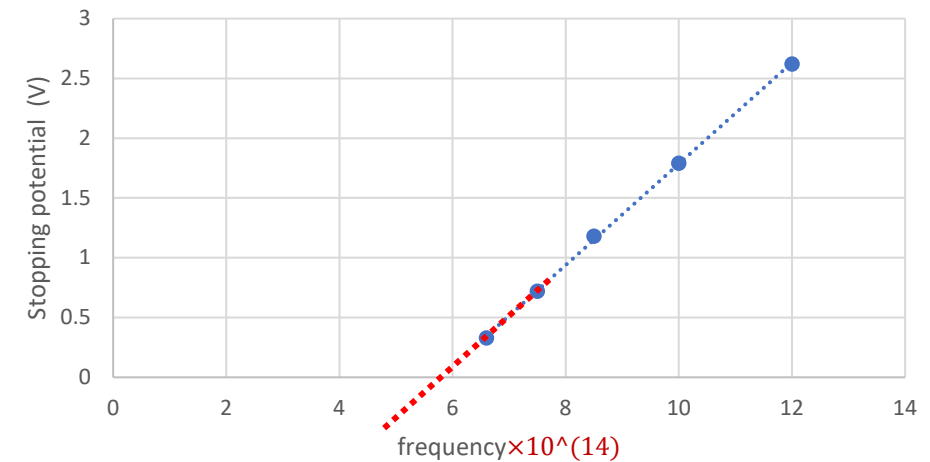
$$f_0 = \frac{W}{h} = \frac{3.84 \times 10^{-19}}{6.63 \times 10^{-34}} = 5.79 \times 10^{14} \text{ Hz}$$

Extend the lines in the graphs find the point where the line intercept with the ($x - axis$) and compare it with the threshold frequency.

Maximum K.E versus frequency



Stopping potential versus frequency



Testing the photon theory:

Conclusion:

1. The slope of the graph Maximum K.E versus frequency equals to

Planks constant (h)

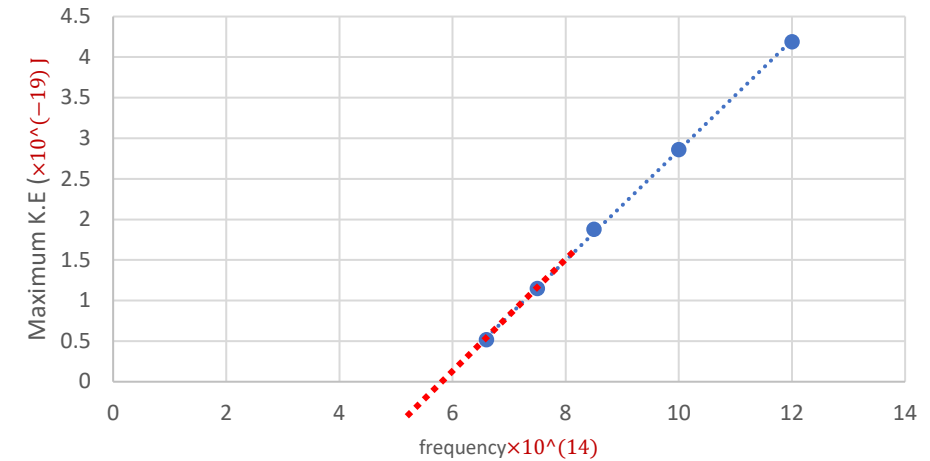
2. The slope of the graph Stopping potential versus frequency equals to

h/e

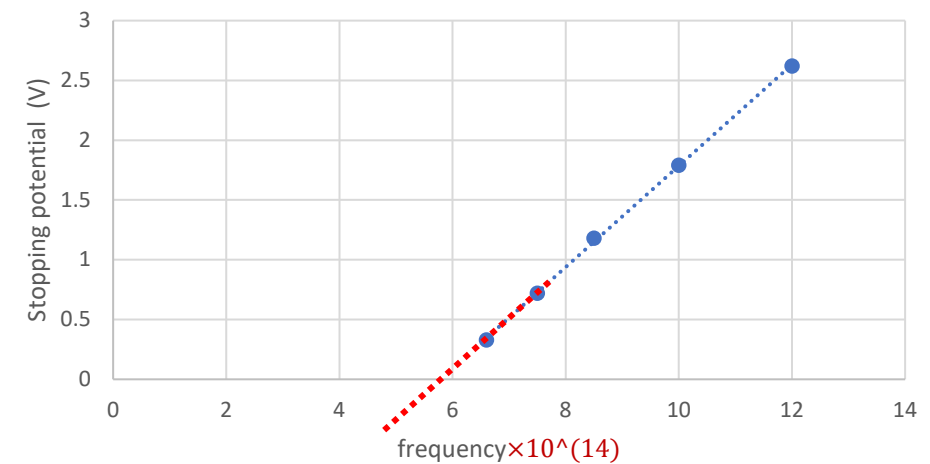
3. The point where the line intercept with the ($x - axis$) is

Threshold frequency

Maximum K.E versus frequency



Stopping potential versus frequency





LO:

7

Describe the de Broglie wavelength as the wavelength associated with a moving particle.

Calculate the de Broglie wavelength for a moving particle ($\lambda = \frac{h}{p} = \frac{h}{mv}$)



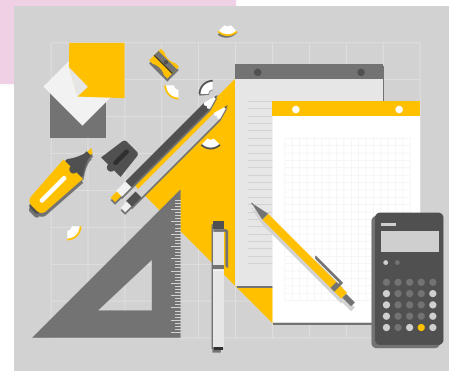
Example
/
Exercise

Example problem 3

P- 80

Practice problems

P- 80





De Broglie Waves:



If an electromagnetic wave can behave like a collection of particles, could a particle exhibit interference and diffraction as a wave does?

In 1923 French physicist Louis de Broglie proposed that a material particle could be described by a wavelength. This proposal was a brave extension of Einstein's photon theory, and Einstein was an early supporter of de Broglie's waves.

The momentum of an object is equal to its mass times its velocity.

$$P = mv$$

If the massive object is also a wave, then its momentum should be like that of a photon.

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

DE BROGLIE WAVELENGTH

The de Broglie wavelength of a moving particle is equal to Planck's constant divided by the particle's momentum.

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

According to de Broglie, **any small particle such as an electron or a proton should show wavelike properties**. In 1927, independent experiments confirmed electron diffraction, which is evidence of electrons' wavelike properties. **Objects you use every day do not exhibit wavelike properties simply because their wavelengths are too small to observe.**



**EXAMPLE PROBLEM 3** (page 80)

DE BROGLIE WAVELENGTH An electron is accelerated by a potential difference of **75 V**. What is its de Broglie wavelength?

$$m_e = 9.11 \times 10^{-31} \text{ kg} \quad e = -1.602 \times 10^{-19} \text{ C} \quad h = 6.63 \times 10^{-34} \text{ J.s}$$

$$K.E = \frac{1}{2}mv^2 = -e\Delta V$$

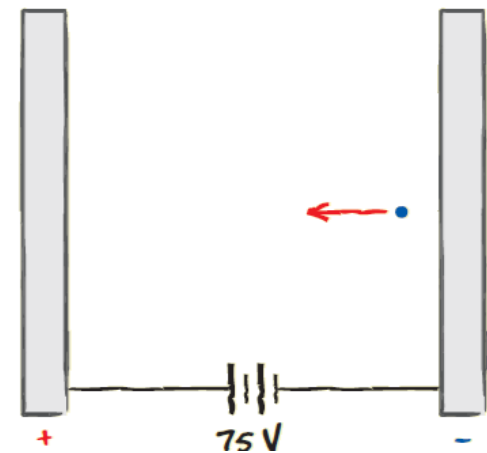
$$v = \sqrt{-\frac{2e\Delta V}{m}}$$

$$v = \sqrt{-\frac{2(-1.602 \times 10^{-19})(75)}{(9.11 \times 10^{-31})}} = 5.1 \times 10^6 \text{ m/s}$$

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

$$\lambda = \frac{6.63 \times 10^{-34}}{(9.11 \times 10^{-31})(5.1 \times 10^6)}$$

$$\lambda = 1.4 \times 10^{-10} \text{ m}$$



**PRACTICE PROBLEMS** (page 80)

25. What is the de Broglie wavelength and speed of an electron accelerated by a potential difference of 250 V?

$$m_e = 9.11 \times 10^{-31} \text{ kg} \quad e = -1.602 \times 10^{-19} \text{ C} \quad h = 6.63 \times 10^{-34} \text{ J.s}$$

$$K.E = \frac{1}{2}mv^2 = -e\Delta V$$

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

$$v = \sqrt{-\frac{2e\Delta V}{m}}$$

$$\lambda = \frac{6.63 \times 10^{-34}}{(9.11 \times 10^{-31})(9.4 \times 10^6)}$$

$$v = \sqrt{-\frac{2(-1.602 \times 10^{-19})(250)}{(9.11 \times 10^{-31})}} = 9.4 \times 10^6 \text{ m/s}$$

$$\lambda = 7.7 \times 10^{-11} \text{ m}$$





PRACTICE PROBLEMS (page 80)

26. A 7.0 kg bowling ball rolls with a velocity of 8.5 m/s.

$$h = 6.63 \times 10^{-34} \text{ J}\cdot\text{s}$$

a. What is the de Broglie wavelength of the bowling ball?

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

$$\lambda = \frac{6.63 \times 10^{-34}}{(7)(8.5)} = 1.1 \times 10^{-35} \text{ m}$$

b. Why does the bowling ball exhibit no observable wave behavior?

The wavelength is too small to show observable effects.



**PRACTICE PROBLEMS** (page 80)

27. What potential difference is needed to accelerate an electron, so it has a 0.125 nm wavelength?

$$m_e = 9.11 \times 10^{-31} \text{ kg} \quad e = -1.602 \times 10^{-19} \text{ C} \quad h = 6.63 \times 10^{-34} \text{ J.s}$$

$$K.E = \frac{1}{2}mv^2$$

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

$$K.E = \frac{\left(\frac{h}{\lambda}\right)^2}{2m}$$

$$K.E = \frac{\left(\frac{6.63 \times 10^{-34}}{0.125 \times 10^{-9}}\right)^2}{2(9.11 \times 10^{-31})} = 1.544 \times 10^{-17} \text{ J}$$

$$K.E = -e\Delta V$$

$$\Delta V = \frac{K.E}{-e}$$

$$\Delta V = \frac{1.544 \times 10^{-17}}{-(-1.602 \times 10^{-19})}$$

$$\Delta V = 96.5 \text{ V}$$



**PRACTICE PROBLEMS** (page 80)

28. CHALLENGE The electron in Example problem 3 has a de Broglie wavelength of **0.14 nm**. What is the kinetic energy, in **eV**, of a **proton** with the same wavelength?

$$m_p = 1.67 \times 10^{-27} \text{ kg} \quad e = -1.602 \times 10^{-19} \text{ C} \quad h = 6.63 \times 10^{-34} \text{ J.s}$$

$$K.E = \frac{1}{2}mv^2$$

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

$$K.E = \frac{\left(\frac{h}{\lambda}\right)^2}{2m}$$

$$K.E = \frac{\left(\frac{6.63 \times 10^{-34}}{0.14 \times 10^{-9}}\right)^2}{2(1.67 \times 10^{-27})} = 6.714 \times 10^{-21} \text{ J}$$

$$K.E = \frac{6.714 \times 10^{-21}}{(1.602 \times 10^{-19})}$$

$$K.E = 4.2 \times 10^{-2} \text{ eV}$$





Extra questions

1. What is the de Broglie wavelength of an electron moving at $3 \times 10^6 m/s$?

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

$$\lambda = \frac{6.63 \times 10^{-34}}{(9.11 \times 10^{-31})(3 \times 10^6)} = 2.4 \times 10^{-10} m$$

2. What velocity would an electron need to have a de Broglie wavelength of $3 \times 10^{-10} m$?

$$v = \frac{h}{m\lambda}$$

$$v = \frac{6.63 \times 10^{-34}}{(9.11 \times 10^{-31})(3 \times 10^{-10})} = 2.4 \times 10^6 m/s$$





LO:

8

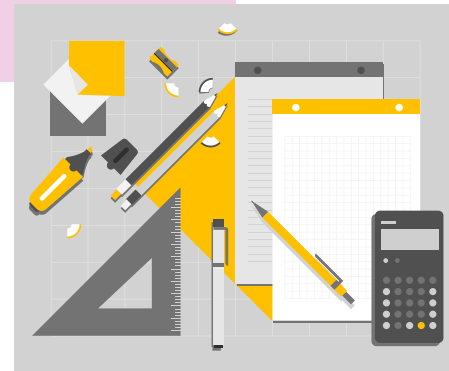
Describe that the more precisely a particle's position is measured, the more the uncertainty in simultaneously measuring the particle's momentum, and vice versa



Example
/
Exercise

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Location And Momentum:

De Broglie's theory of particles' wavelike properties led to a fundamental change in our understanding of atomic-sized objects.

In everyday experience, it is logical to think that you can measure any property to any desired level of precision.

For example, imagine measuring a ball's position during free fall. You might first try using a meterstick and a stopwatch to make the measurements. If you desire more precise measurements, you might use a video camera and a calculator or a computer. You can imagine using more and more sophisticated equipment to achieve ever greater precision. In fact, classical physics sets no limit on a measurement's precision.

Types of Measuring Tools



de Broglie's revolutionary theory of matter waves forced physicists to redefine the limits of measurement.

Heisenberg uncertainty principle:

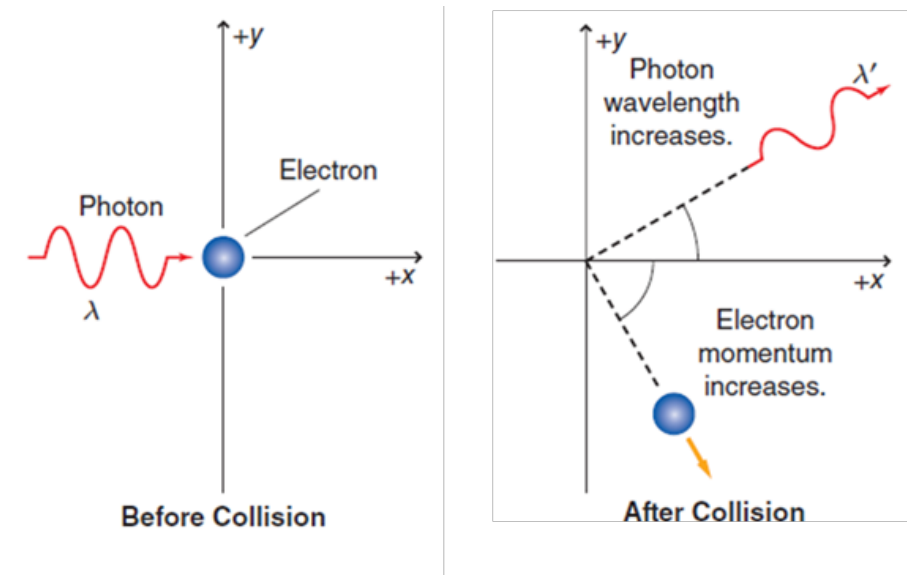
Consider measuring the location of an atomic or subatomic scale particle by shining light on it and then collecting the reflected light in a measuring device.

- Because of diffraction, the reflected light you use to detect the particle spreads out and makes it impossible to locate the particle exactly.
- If more precise measurements are needed, you can use shorter-wavelength radiation, which decreases diffraction and decreases the uncertainty in the particle's location.

As a result of the Compton effect, however, when short wavelength, high-energy radiation strikes a particle, the particle's momentum is changed.

Therefore, the act of measuring the location of a particle has the effect of changing the particle's momentum.

The more precise the determination of a particle's location, the greater the uncertainty is in its momentum. Similarly, if the momentum of the particle is precisely known, the position of the particle becomes less certain.



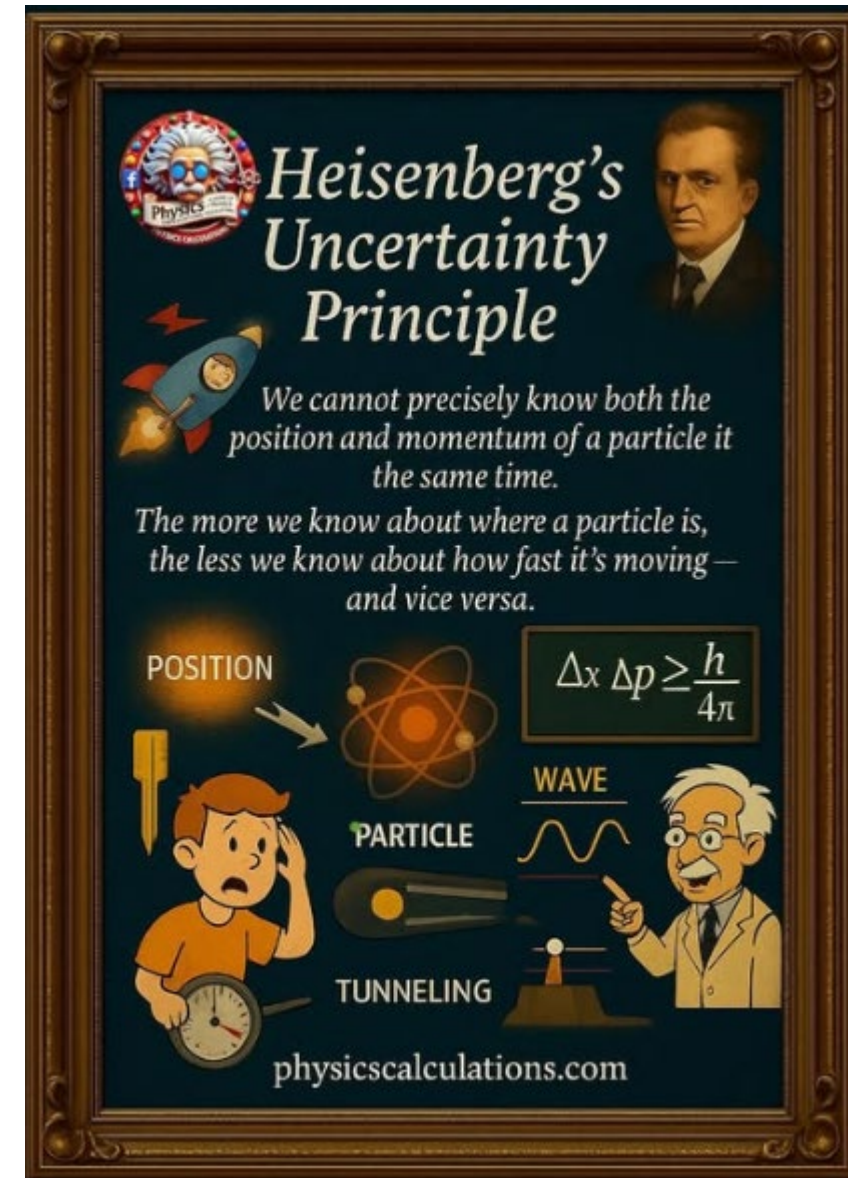
Heisenberg uncertainty principle:

This situation is summarized by the **Heisenberg uncertainty principle**, which states there is a limit to how precisely a particle's position and momentum can simultaneously be measured.

This principle, named for German physicist Werner Heisenberg, is the result of light and matter's dual wavelike and particle-like properties.

Even though the effects of the limit are only noticeable when measuring atomic-scale particles, Heisenberg's work led to a fundamental change in our understanding of the world.

While the classical theories of Newton and Maxwell are successful models of everyday objects, quantum theory and its models of the dual nature of light and matter are required to accurately describe objects on the atomic scale.





Check Your Progress (page 81)

32. Critical Thinking How does the Heisenberg uncertainty principle explain double slit, interference pattern even if photons or atoms pass through the slits one at a time.

The Heisenberg uncertainty principle states that you cannot simultaneously know the precise position and momentum of a particle.

Thus, if you know the precise position of a photon or an atom as it passes through the slit, you cannot know its precise momentum.

Because of the unknown momentum, you cannot be sure which of the slits the beam passed through, resulting in the distribution of photons or atoms seen in the interference pattern.





LO:

9

Describe the electron distribution within the atom according to Thomson's model.

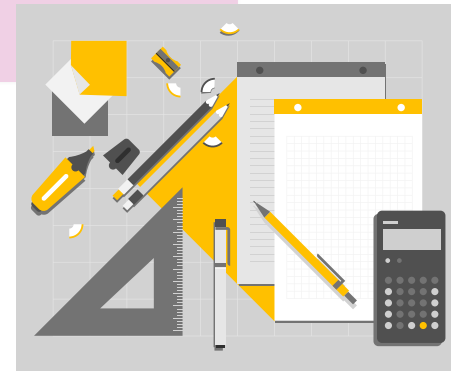
Describe how Rutherford's alpha particles scattering experiment led to the revision of Thomson's model of the atom and the introduction of the atomic nucleus



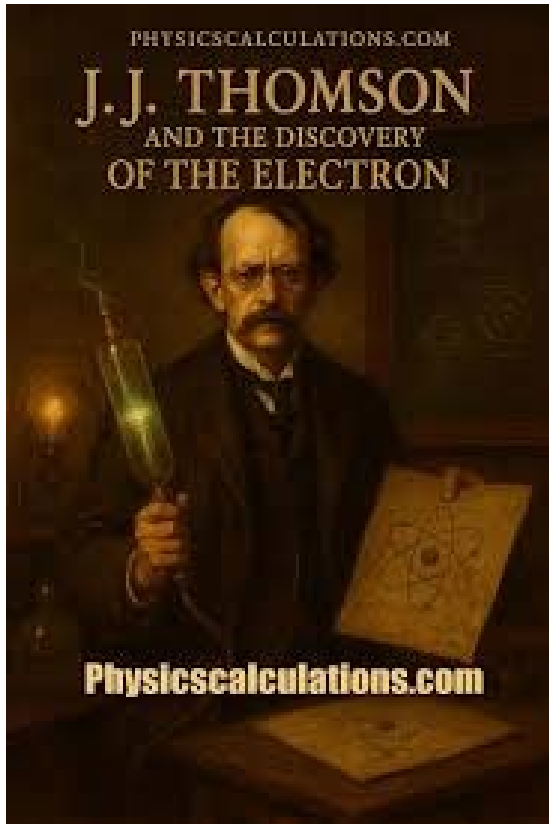
Example
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Thomson's model:



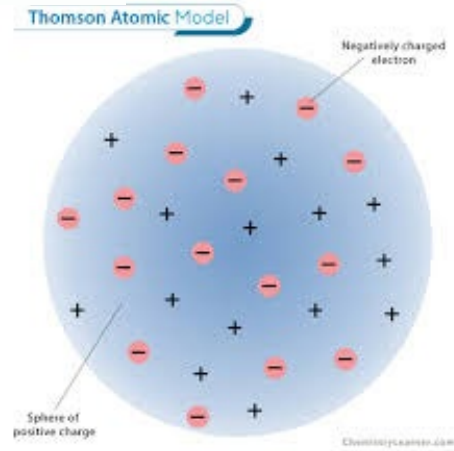
J.J. Thomson's and the discovery of the electron.

The discovery of the electron provided convincing evidence that the atom must be made of even **smaller, subatomic particles**



Congratulations Mr. Thomson

Do you have a conception of what an atom looks like?



The atom look like raisins in a muffin:

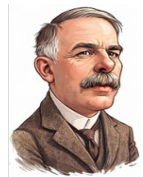
A massive, **positively charged substance** filled the atom.

And the **negatively charged electrons** as being distributed throughout this positively charged substance.



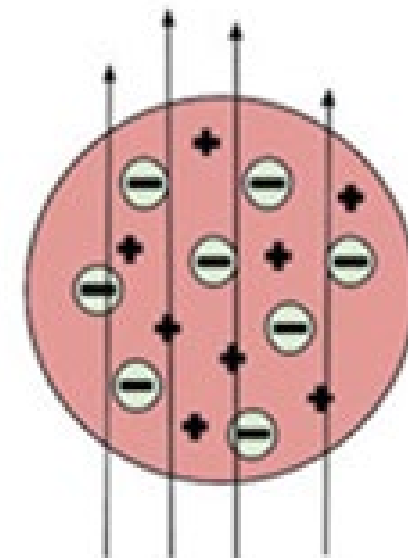


Testing Thomson's model (Rutherford's investigation):



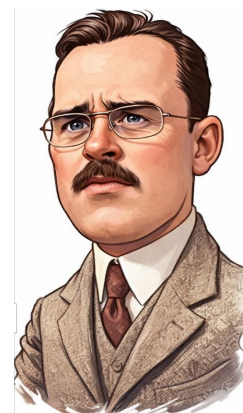
If we directed a beam of **α -particles** at an atom, based on Thomson's model of the atom, we expected only **minor deflections of the α -particles** as they pass through the atom.

He hypothesized that the **paths of the massive, high-speed α -particles would be only slightly altered** as they passed through the evenly distributed positive charge making up each atom.



Expected results of the gold foil experiment—all alpha particles pass through atoms in the gold foil.

Nice!
Let's design an experiment



Ernest Marsden



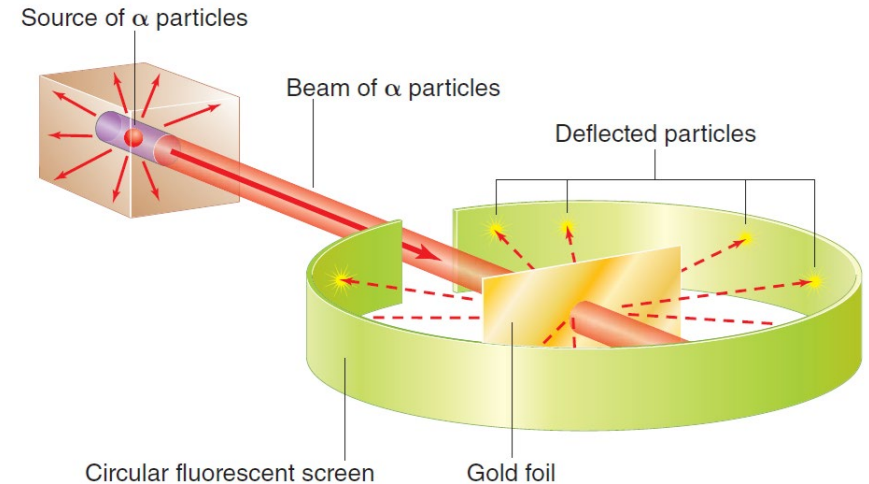
Hans Geiger



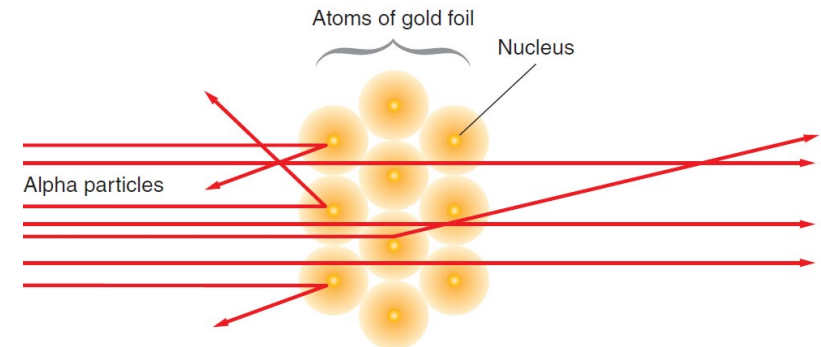
Testing Thomson's model (Rutherford's investigation):

Test results:

- Most of the α -particles passed through the gold foil either undeflected or only slightly deflected.
- A few of the particles were scattered through very large angles.
- Some even rebounded through angles larger than 90° .



Thomson model
is not accurate!





Extra questions

1. What evidence did the alpha scattering experiment give for the nucleus being positively charged?

A- alpha particles moved randomly without deflection

B- the foil emitted flashes of light when struck

C- most alpha particles passed straight through the foil

D- alpha particles were repelled and deflected at large angles

2. Why were alpha particles chosen for Rutherford's experiment?

A- They move slowly and are easily deflected.

B- They are negatively charged and lightweight.

C- They are neutral and pass through matter easily.

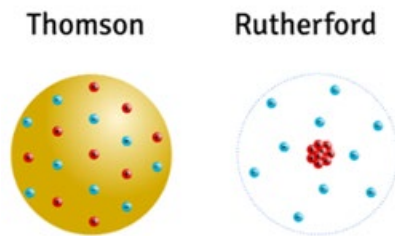
D- They are massive and positively charged.





Extra questions

3. Which experimental result from Rutherford's gold foil experiment most strongly required scientists to drop Thomson's plum pudding model?



A- A small fraction of alpha particles were deflected at angles greater than 90° .

B- The majority of alpha particles passed through the foil without deflection.

C- Alpha particles were detected as flashes on a zinc-sulfide screen.

D- Gold atoms were electrically neutral.

4. Which statement is consistent with Rutherford's conclusions?

A- The nucleus contains most of the atom's mass and the atom is mainly made from empty space.

B- The atom's mass and charge are equally distributed within the atom.

C- The atom is a solid sphere.

D- The nucleus contains most of the atom's mass and the atom is mainly made from positive charge.

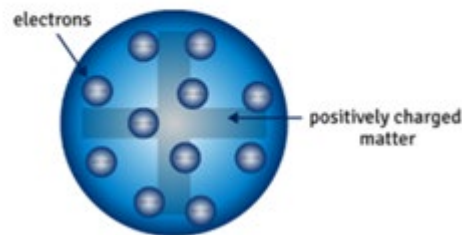




Extra questions

5. Which observation from the gold foil experiment most directly contradicts Thomson's plum pudding model?

plum pudding model



A- Gold atoms contain electrons.

B- A small fraction of alpha particles were deflected at large angles.

C- Most alpha particles passed straight through the foil.

D- Alpha particles are positively charged.

6. **Describe** how Rutherford determined that the positive charge in an atom is concentrated in a tiny region, rather than spread throughout the atom.

He directed a beam of charged particles at a thin metal sheet and measured the number of particles deflected at various angles.

The small but significant number depleted at wide angles indicates a concentrated nucleus.





Get It?

Explain why Rutherford was so surprised by the results of the gold leaf experiment.

He was expecting the α -particles to be slightly deflected according to Thomson's model of the atom, in which the positive charge was evenly distributed throughout the atom.

Instead, the particles were mostly undeflected, but a few were deflected at large angles.





Check Your Progress (page 94)

41. Rutherford's Nuclear Model Summarize the structure of the atom according to Rutherford's nuclear model.

In Rutherford's nuclear model, all of an atom's positive charge and virtually all of its mass are concentrated in a tiny, centrally located nucleus around which negatively charged electrons orbit.





LO:

10

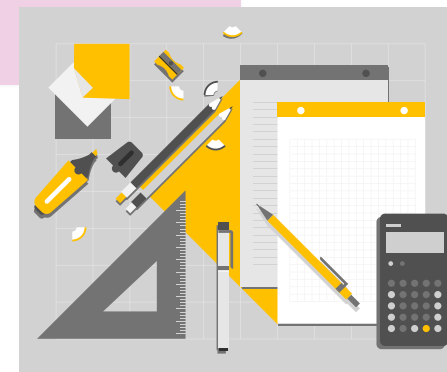
Explain how the composition of an unknown gas sample can be determined using its emission and absorption spectrum



Example
/
Exercise

St. textbook

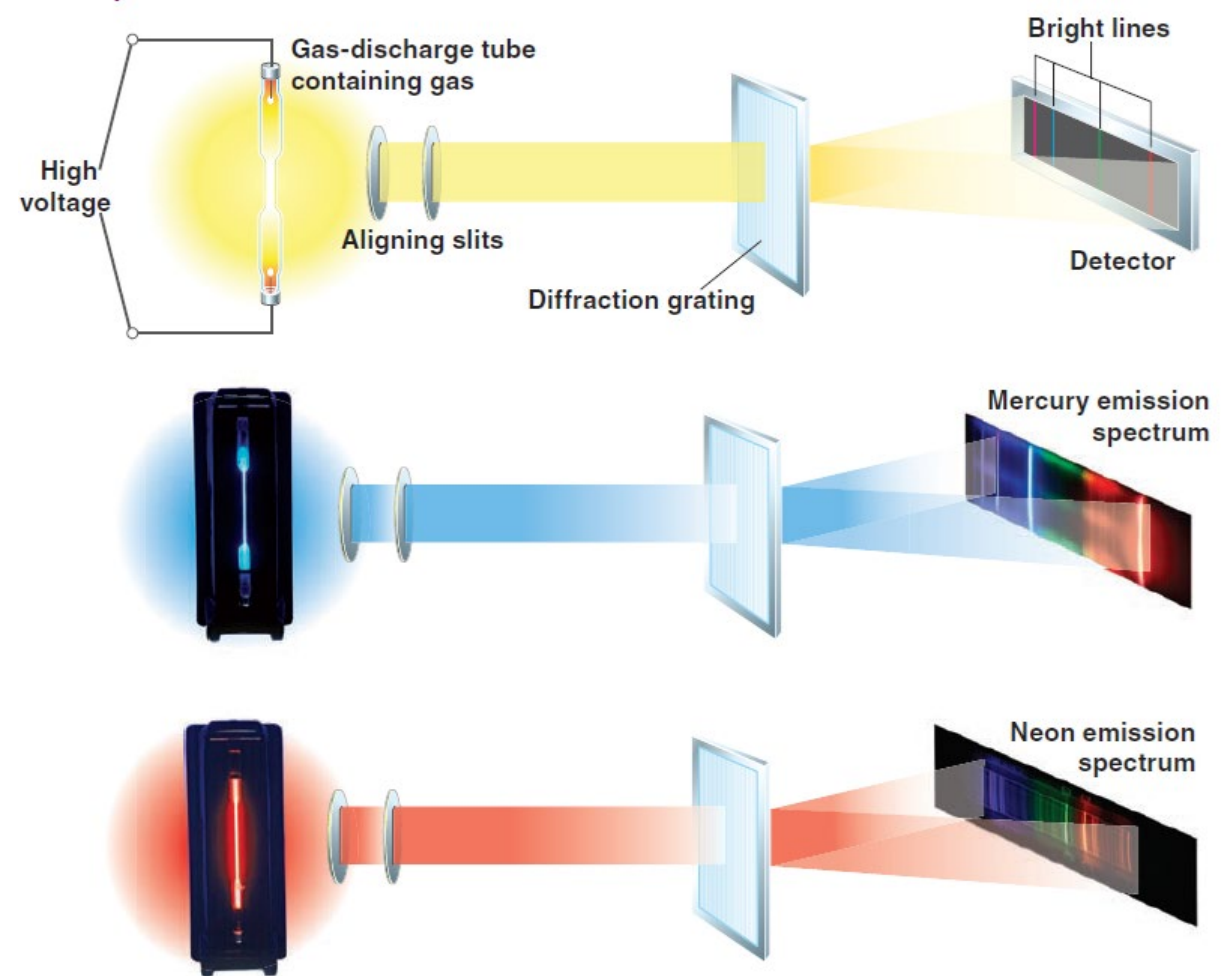
P- 84-85



Emission spectra:

As you may have read in an earlier chapter, the spectrum of an incandescent (**glowing**) solid, such as a lightbulb filament, is a continuous band of colors from red through violet.

The spectrum of a gas, however, is a series of distinct lines of different colors



Each colored line corresponds to a particular wavelength of light emitted by the atoms of that gas.

Emission spectra (Identifying unknown samples) :



How can scientists benefit from emission spectrum?

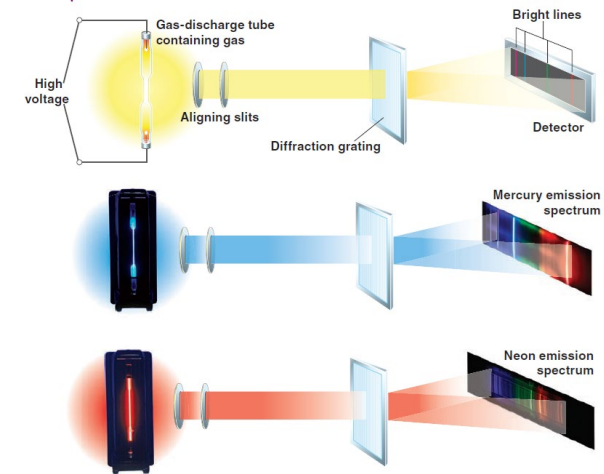
An emission spectrum is a useful analytic tool that can be used to **identify** an unknown sample of gas.

- 1- When an unknown gas is placed in a gas-discharge tube, it can be made to emit light.
- 2- The emitted light includes combinations of wavelengths that are uniquely characteristic of the atoms of that gas.
- 3- Thus, the unknown gas can be identified by comparing its wavelengths with the wavelengths measured in the spectra of known gas samples.

When the emission spectrum of a combination of elements is **photographed**, an **analysis of the lines** on the photograph can **indicate** the **identities** and the relative **concentrations** of the elements present.

The elements that are present in the **greatest concentrations** produce emission lines of **greater relative intensities**.

Through a comparison of the line intensities, the percentage composition of the gaseous material can be determined. This type of analysis is used daily to solve problems in **chemistry, engineering, medicine, and environmental science**.





Get It?

Explain how an emission spectrum can help to identify the composition and concentrations of elements in a sample.

The presence of coloured lines determines the composition of elements.

The intensities of the lines determine the concentration.





Get It?

Describe how scientists are able to determine the composition of stars.

They compare the absorption spectra of the stars with known emission spectra of various elements.





LO:

11

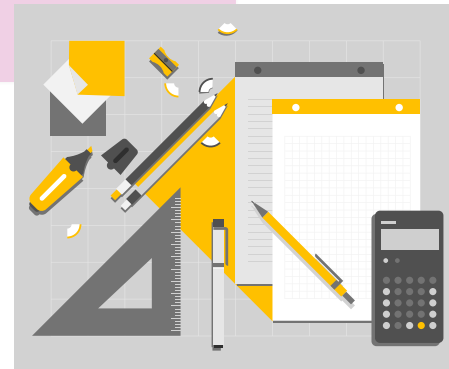
Explain that the absorption spectrum of an element is a unique pattern, which serves as a fingerprint of that element



Example
/
Exercise

St. textbook

P- 85-86



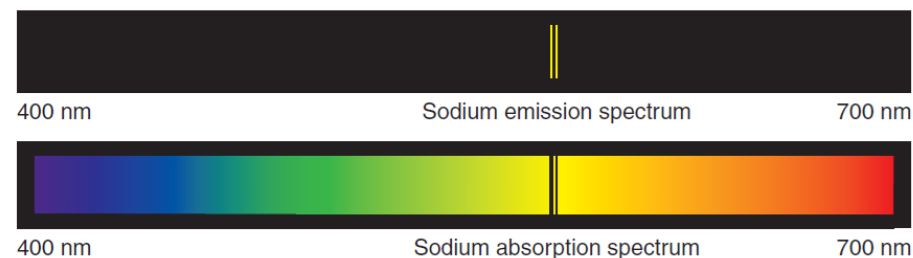
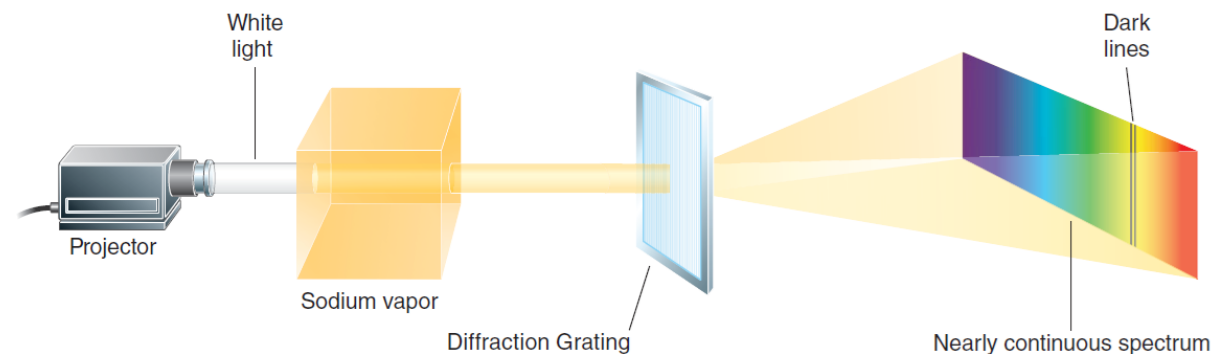


Absorption spectra:



Another technique used to identify unknown samples.

Passing **white light** through a **gas sample** and then through a **prism** results in the normally **continuous spectrum of white light**, but with **dark lines** in it corresponding to **wavelengths of light absorbed** by the gas.



The set of wavelengths absorbed by a gas is the **absorption spectrum** of the gas.

For a gas, the bright lines of the emission spectrum and the dark lines of the absorption spectrum occur at the same wavelengths,

Thus, cool, gaseous elements absorb the same wavelengths that they emit when excited.

The composition of a gas can be determined from the wavelengths of the dark lines of the gas's absorption spectrum.





Check Your Progress (page 94)

43. Spectra How do the emission spectra of incandescent solids and atomic gases differ? In what ways are they similar?

Incandescent solids produce spectra consisting of a continuous band of colors, whereas gases produce spectra made up of a set of discrete lines.

All spectra are created by energy-level transitions in atoms.





LO:

12

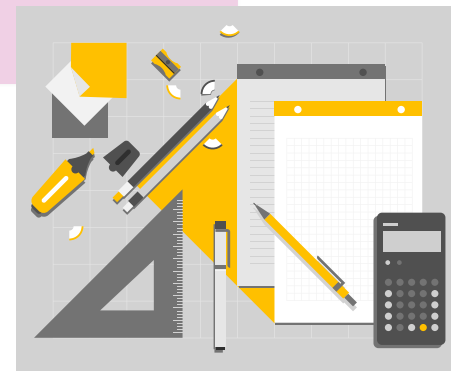
Explain that an atom can transition from an initial energy state (E_i) to a final energy state (E_f) by absorbing or emitting a photon whose energy equals the difference between the two states.



Example
/
Exercise

St. textbook

P- 85-86





Energy of an atom:



Mr. Bohr ! If stable atoms do not radiate energy.

What is responsible for an atom's characteristic emission spectrum?



Electromagnetic energy is emitted when the atom changes from **one state to another**.

Incorporating Einstein's theory

$$E_{\text{photon}} = hf.$$

When an atom absorbs a photon, the atom's **energy increases** by an amount equal to that of the photon.

When this excited atom makes a transition to a lower energy level, it emits a photon.

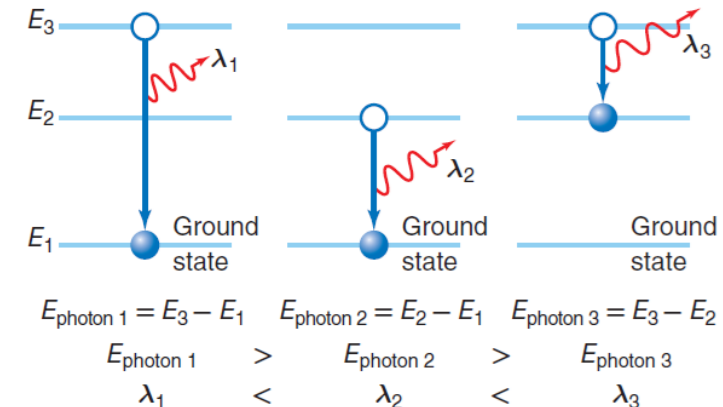
When the atom makes the transition from its initial energy level (E_i) to its final energy level (E_f) the change in energy (ΔE_{atom}) is given by the following equation:

$$\Delta E_{\text{atom}} = E_f - E_i$$

$$\Delta E_{\text{atom}} = -E_{\text{photon}}$$

$$E_{\text{photon}} = hf = -\Delta E_{\text{atom}}$$

The energy of the atom decreases equals the energy of the emitted photon.





LO:

13

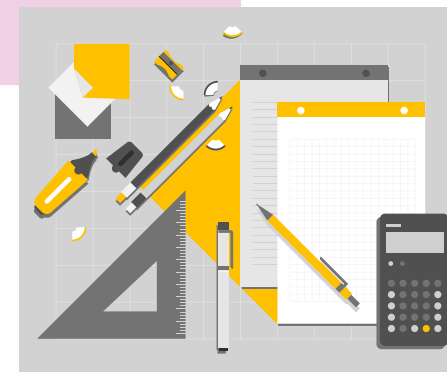
Describe Rutherford's nuclear model of the atom, as a small dense positively charged nucleus surrounded by orbiting electrons (planetary model), and explain why this model cannot explain the stability and the observed line emission spectra of atoms.



Example
/
Exercise

St. textbook

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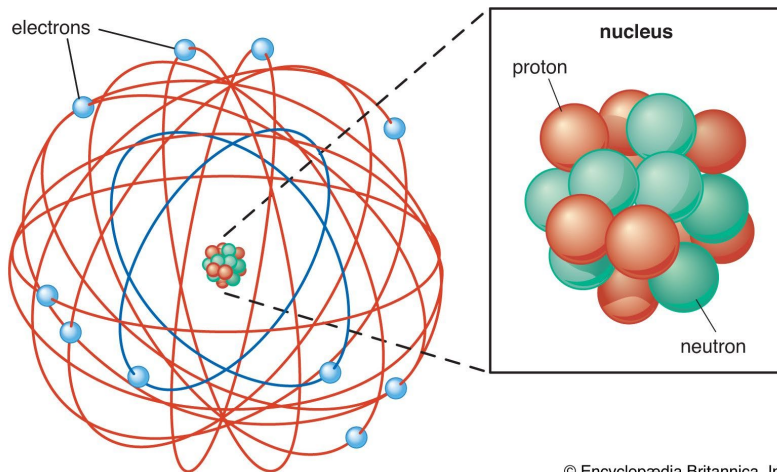


Rutherford's revised model of the atom:



Congratulations Mr. Rutherford

Do you have a conception of what an atom looks like?

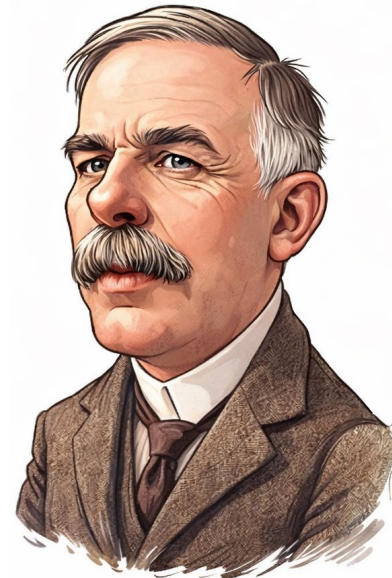


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Nuclear model (planetary model):

Using Coulomb's law for the force between charged objects and Newton's laws of motion

Rutherford concluded that the results could be explained if all of an atom's positive charge were concentrated in a tiny, massive core, **which is now called the nucleus.**



Ernest Rutherford



Rutherford's revised model of the atom:



- Researchers have since determined that all the positive charge and more than 99.9% of an atom's mass are **contained in its nucleus**.



- The electrons do **not contribute a significant amount of mass** to the atom and are distributed through a large volume that stretches far away from the nucleus.



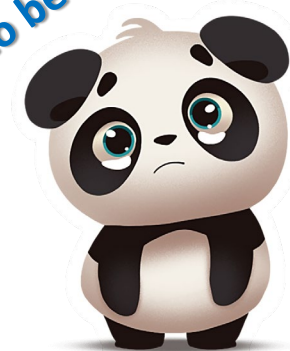
- The volume occupied by the electrons defines **the overall size**, or diameter, of the atom, which is about 50,000 times larger than the diameter of the nucleus.



- An atom is mostly **empty space**.



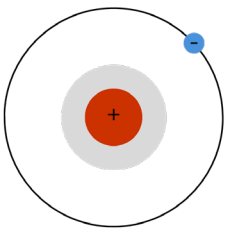
Not good enough to be revised later!



Revising Rutherford's Nuclear Model:

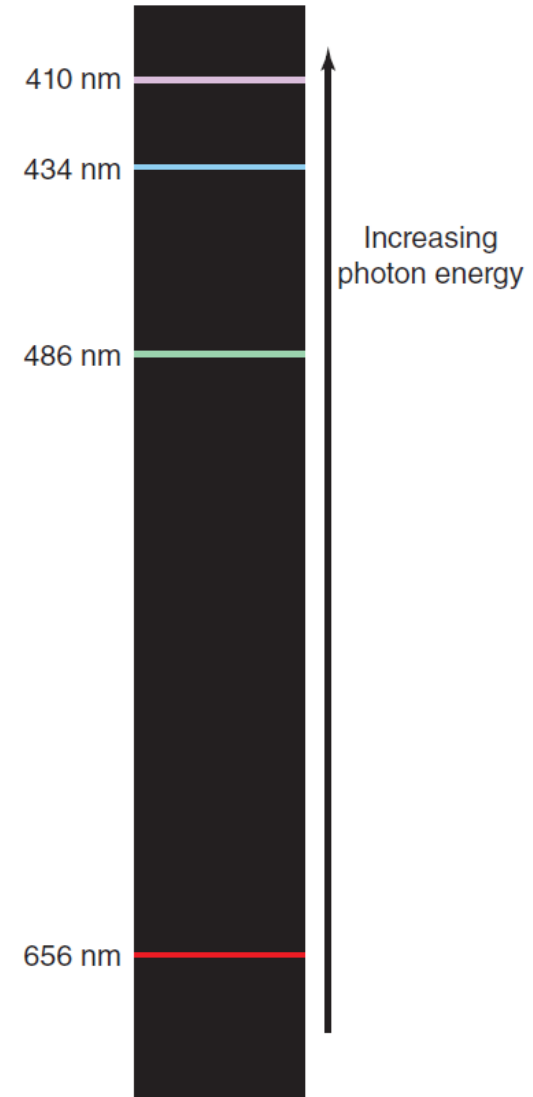
 In the nineteenth century, many physicists studied atomic spectra to determine the structure of the atom.

Hydrogen Atom



Hydrogen was studied extensively because it is the **lightest** element and has the **simplest spectrum**.

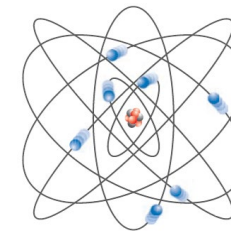
The visible spectrum of hydrogen consists of four lines: **red**, **green**, **blue**, and **violet**, as shown.



Any theory that explained the structure of the atom would have to **account** for these wavelengths, as well as support the **nuclear model** of the atom.

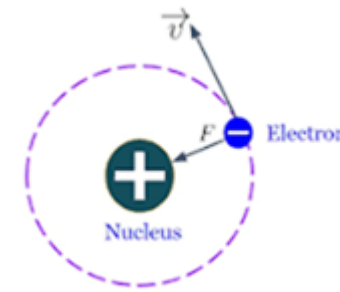


The nuclear model as proposed by Rutherford was not without its problems, however. Rutherford had suggested that electrons orbit the nucleus much like the planets orbit the Sun. **There was, however, a serious flaw in this planetary model.**



Problems with the planetary model:

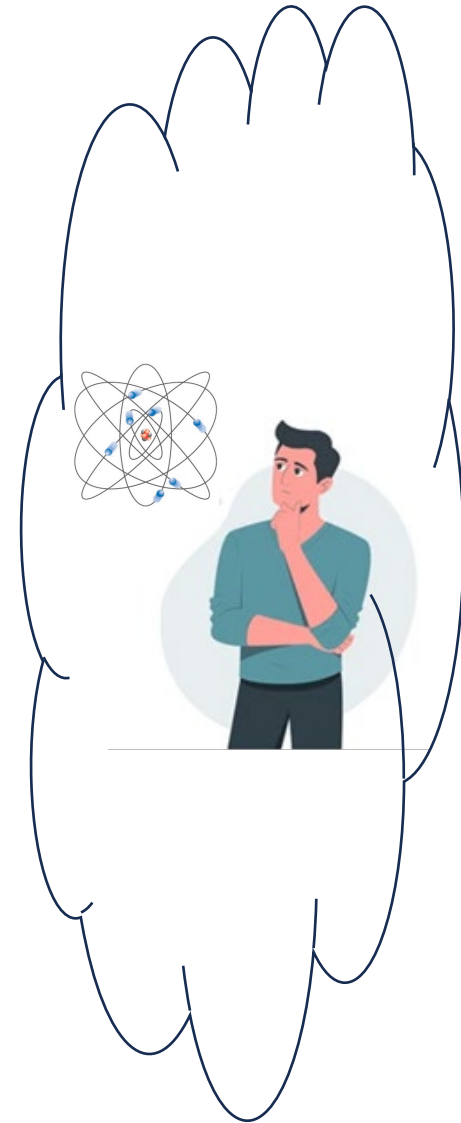
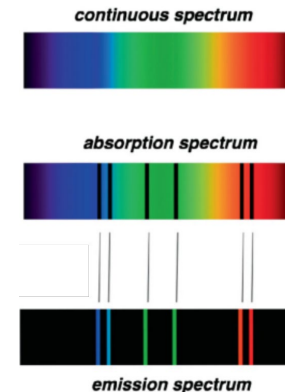
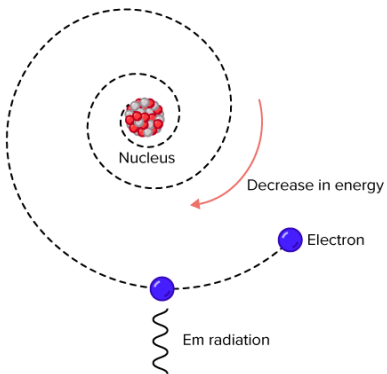
- An electron in an orbit constantly accelerates toward the nucleus.



- Accelerating electrons radiate energy by emitting electromagnetic waves. At the rate that an orbiting electron would lose energy, it should spiral into the nucleus within a fraction of a second.

But we know that atoms are stable, so the planetary model does not agree with the laws of electromagnetism.

- In addition, the planetary model predicted that the accelerating electrons would radiate energy at all wavelengths. However, as you just read, the light emitted by atoms is radiated only at specific wavelengths.

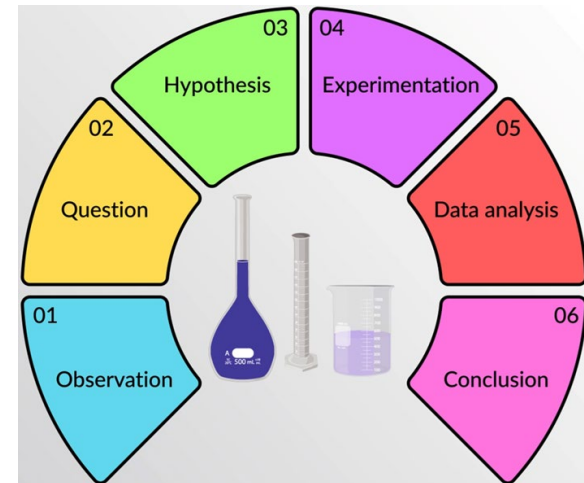


Predictions of the Bohr Model:



A scientific theory must do more than present postulates; it must allow predictions to be made that can be checked against experimental data.

A good theory also can be applied to many different problems, and it ultimately provides a simple, unified explanation of some part of the physical world.



Bohr used his theory to calculate the wavelengths of light emitted by a hydrogen atom.



The calculations were in excellent agreement with the values measured by other scientists.



As a result of this agreement between Bohr's predictions and the measured values, Bohr's model was widely accepted.



Unfortunately, the model only **worked for the element hydrogen**; it **could not** predict the spectrum of helium, the next-simplest element.

In addition, there was **not a good explanation** as to why the laws of electromagnetism should work everywhere but inside the atom.



Extra questions

7. Review the planetary model of the atom. What are some of the problems with a planetary model of the atom?

As the electrons undergo centripetal acceleration, they would lose energy and spiral into the nucleus. In addition, all atoms should radiate at all wavelengths, not discrete wavelengths.





Extra questions

1. How does the Bohr model explain why the absorption spectrum of hydrogen contains exactly the same wavelengths as its emission spectrum?

Bohr said the energy of an emitted photon or an absorbed photon is equal to the change in energy of the atom, which can have only specific values.

2. **Gas-Discharge Tubes** Describe how line spectra from gas-discharge tubes are produced.

Energy is supplied to the gas, which causes the electrons to excite and move to higher energy levels.

The electrons then give off the difference in energy between energy levels as they drop back down to a less excited state.

The energy differences between levels corresponds to spectral lines.





Extra questions

3. How does the Bohr model account for the spectra emitted by atoms?

Photon wavelengths are determined by the difference in energies of allowed levels as electrons jump inward to stationary states.

4. Explain why line spectra produced by hydrogen gas-discharge tubes are different from those produced by helium gas-discharge tubes.

Each element has a different configuration of electrons and energy levels.





Extra questions

5. Bohr Model Limitations Although it was able to accurately predict the behavior of hydrogen, in what ways did Bohr's atomic model have serious shortcomings?

The Bohr model could not predict the behavior of any other atom besides hydrogen. The model also could not explain why the laws of electromagnetism do not apply within the atom.





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14

Calculate the total energy of a Hydrogen atom

Describe that the radius of the electron's orbit in Hydrogen atom is proportional to n^2 , while the energy of the atom is inversely proportional to n^2



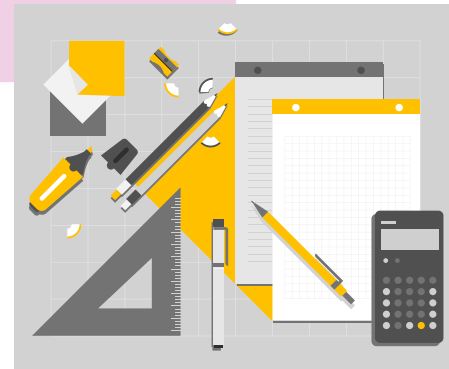
Example
/
Exercise

Example problem 4

Practice problems

P- 92

P- 92





LO:

16

Calculate the energy, frequency, and wavelength of an emitted or absorbed photon as an atom transition from an initial energy level to a final energy level



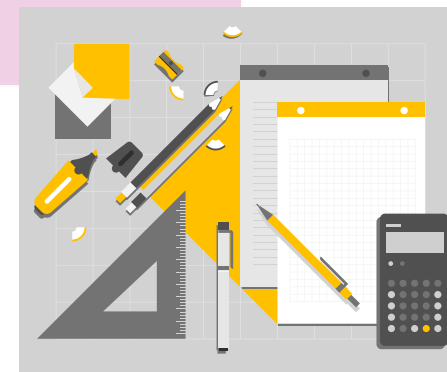
Example
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Exercise

Example problem 5

Practice problems

P- 93

P- 93

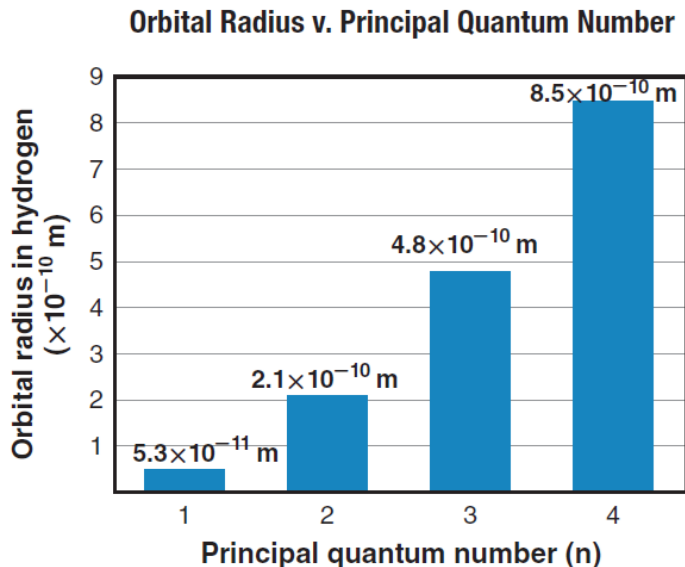




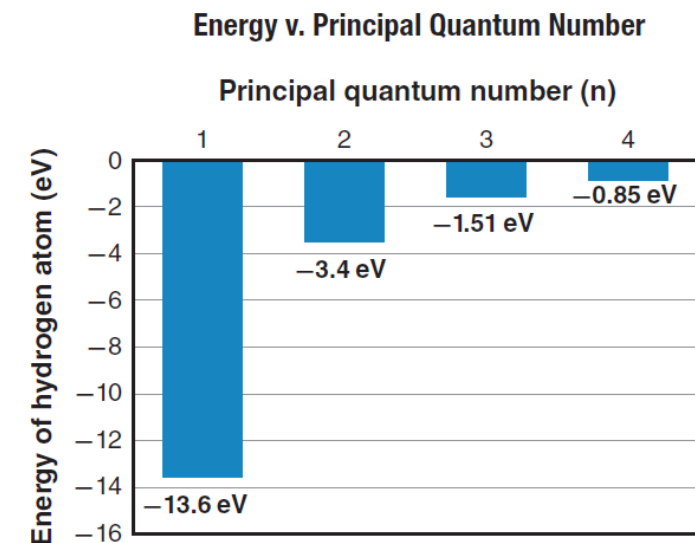
Describe how the orbital radius and the energy depend on the principal quantum number.

The electron's orbital radius (r) increases as the square of n .
the radius of the electron's orbit in Hydrogen atom is proportional to n^2

The energy (E) of the hydrogen atom depends on $\frac{1}{n^2}$.
the energy of the atom is inversely proportional to n^2



As the magnitude of the atom's energy decreases, the electron's orbital radius increases.



**EXAMPLE PROBLEM 4** (page 92)

ENERGY LEVELS In order for an electron in a hydrogen atom to move from the lowest energy level ($n = 1$) to the second energy level ($n = 2$), the atom must absorb energy. Determine the energy of the first and second energy levels and the energy absorbed by the atom.

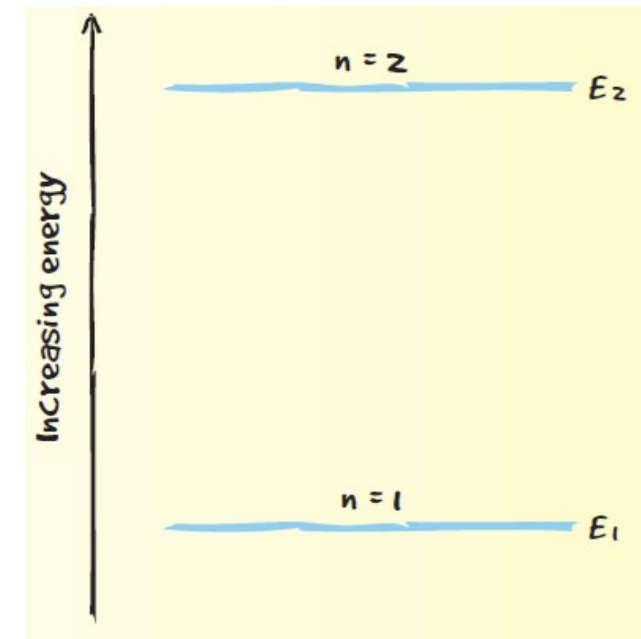
$$E_n = -(13.6 \text{ eV}) \frac{1}{n^2}$$

$$E_1 = -(13.6 \text{ eV}) \frac{1}{1^2} = -13.6 \text{ eV}$$

$$E_2 = -(13.6 \text{ eV}) \frac{1}{2^2} = -3.4 \text{ eV}$$

$$\Delta E = E_2 - E_1$$

$$\Delta E = (-3.4 \text{ eV}) - (-13.6 \text{ eV}) = 10.2 \text{ eV}$$



**PRACTICE PROBLEMS** (page 92)

33. Calculate the energies of the **second**, **third**, and **fourth** energy levels in the hydrogen atom.

$$E_2 = -(13.6 \text{ eV}) \frac{1}{2^2} = -3.4 \text{ eV}$$

$$E_3 = -(13.6 \text{ eV}) \frac{1}{3^2} = -1.51 \text{ eV}$$

$$E_4 = -(13.6 \text{ eV}) \frac{1}{4^2} = -0.850 \text{ eV}$$

34. Calculate the energy difference between E_3 and E_2 in the hydrogen atom.

$$\Delta E = E_3 - E_2$$

$$\Delta E = -(13.6 \text{ eV}) \left(\frac{1}{3^2} - \frac{1}{2^2} \right) = 1.89 \text{ eV}$$

35. Calculate the energy difference between E_4 and E_2 in the hydrogen atom.

$$\Delta E = E_4 - E_2$$

$$\Delta E = -(13.6 \text{ eV}) \left(\frac{1}{4^2} - \frac{1}{2^2} \right) = 2.55 \text{ eV}$$



**PRACTICE PROBLEMS** (page 92)

36. CHALLENGE The text shows the solution of the $r_n = \frac{h^2 n^2}{4\pi^2 k m_e e^2}$ for $n = 1$, the innermost orbital radius of the hydrogen atom. Note that with the exception of n , all factors in the equation are constants. The value of r_1 is $(5.3 \times 10^{-11} \text{ m or } 0.053 \text{ nm})$. Use this information to calculate the radii of the second, third, and fourth energy levels in the hydrogen atom.

$$r_n = \frac{h^2 n^2}{4\pi^2 k m_e e^2}$$

$$r_n = \left(\frac{h^2}{4\pi^2 k m_e e^2} \right) n^2$$

$$r_1 = \left(\frac{h^2}{4\pi^2 k m_e e^2} \right) 1^2 = 5.3 \times 10^{-11} \text{ m}$$

$$r_2 = (5.3 \times 10^{-11}) 2^2 = 2.1 \times 10^{-10} \text{ m}$$

$$r_3 = (5.3 \times 10^{-11}) 3^2 = 4.8 \times 10^{-10} \text{ m}$$

$$r_4 = (5.3 \times 10^{-11}) 4^2 = 8.5 \times 10^{-10} \text{ m}$$



**EXAMPLE PROBLEM 5** (page 93)

FREQUENCY AND WAVELENGTH OF EMITTED PHOTONS An excited hydrogen atom drops from the second energy level ($n = 2$) to the first energy level ($n = 1$). Calculate the energy and the wavelength of the emitted photon. Use E_1 and E_2 values from Example Problem 1.

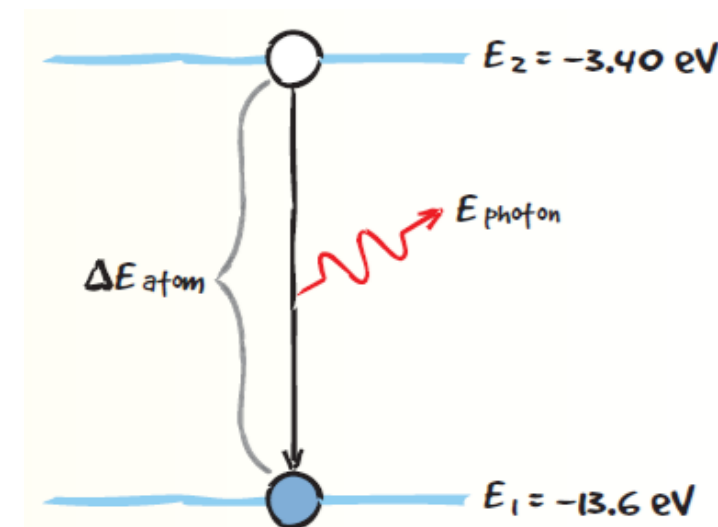
$$\Delta E = E_1 - E_2$$

$$\Delta E = (-13.6 \text{ eV}) - (-3.4 \text{ eV}) = -10.2 \text{ eV}$$

$$\Delta E = hf = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{\Delta E}$$

$$\lambda = \frac{(6.63 \times 10^{-34})(3 \times 10^8)}{(10.2)(1.6 \times 10^{-19})} = 122 \text{ nm}$$



**PRACTICE PROBLEMS** (page 93)

37. Find the wavelength of the light emitted in Practice Problems 34 and 35. Which lines in **Figure 6** correspond to each transition?

$$\lambda_{34} = \frac{hc}{\Delta E}$$

$$\lambda_{34} = \frac{(6.63 \times 10^{-34})(3 \times 10^8)}{(1.89)(1.6 \times 10^{-19})} = 658nm$$

$$\lambda_{35} = \frac{hc}{\Delta E}$$

$$\lambda_{35} = \frac{(6.63 \times 10^{-34})(3 \times 10^8)}{(2.55)(1.6 \times 10^{-19})} = 488nm$$

38. For a particular transition, the energy of a mercury atom drops from 8.82 eV to 6.67 eV.

a. What is the energy of the photon emitted by the mercury atom?

$$\Delta E = E_2 - E_1$$

$$\Delta E = (6.67eV) - (8.82) = -2.51 eV$$

b. What is the wavelength of the photon emitted by the mercury atom?

$$\lambda = \frac{hc}{\Delta E}$$

$$\lambda = \frac{(6.63 \times 10^{-34})(3 \times 10^8)}{(2.15)(1.6 \times 10^{-19})} = 578nm$$



**PRACTICE PROBLEMS** (page 93)

39. CHALLENGE The ground state of a helium ion is -54.4 eV . A transition to the ground state emits a 304 nm photon. What was the energy of the excited state?

$$\lambda = \frac{hc}{\Delta E}$$

$$\lambda = \frac{(6.63 \times 10^{-34})(3 \times 10^8)}{(304 \times 10^{-9})(1.6 \times 10^{-19})} = 4.08 \text{ nm}$$

$$E_{\text{excited}} = E_{\text{ground}} + \Delta E$$

$$E_{\text{excited}} = -54.4 + 4.08 = -50.3 \text{ eV}$$





LO:

15

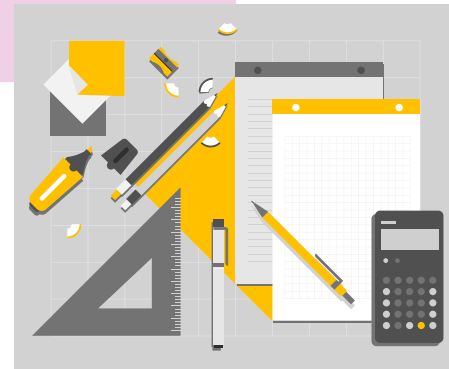
Explain that the Lyman, Balmer and Paschen series and the energy levels and transitions correspond to them



Example
/
Exercise

St. textbook

P- 91



Energy and electron transitions:



Some of hydrogen's energy levels and the possible energy level transitions that it can undergo.

Lyman series

Ultraviolet light is emitted when the atom drops into its ground state from any excited state.

$$n = 2, 3, 4 \dots \text{to } n = 1$$

Balmer series

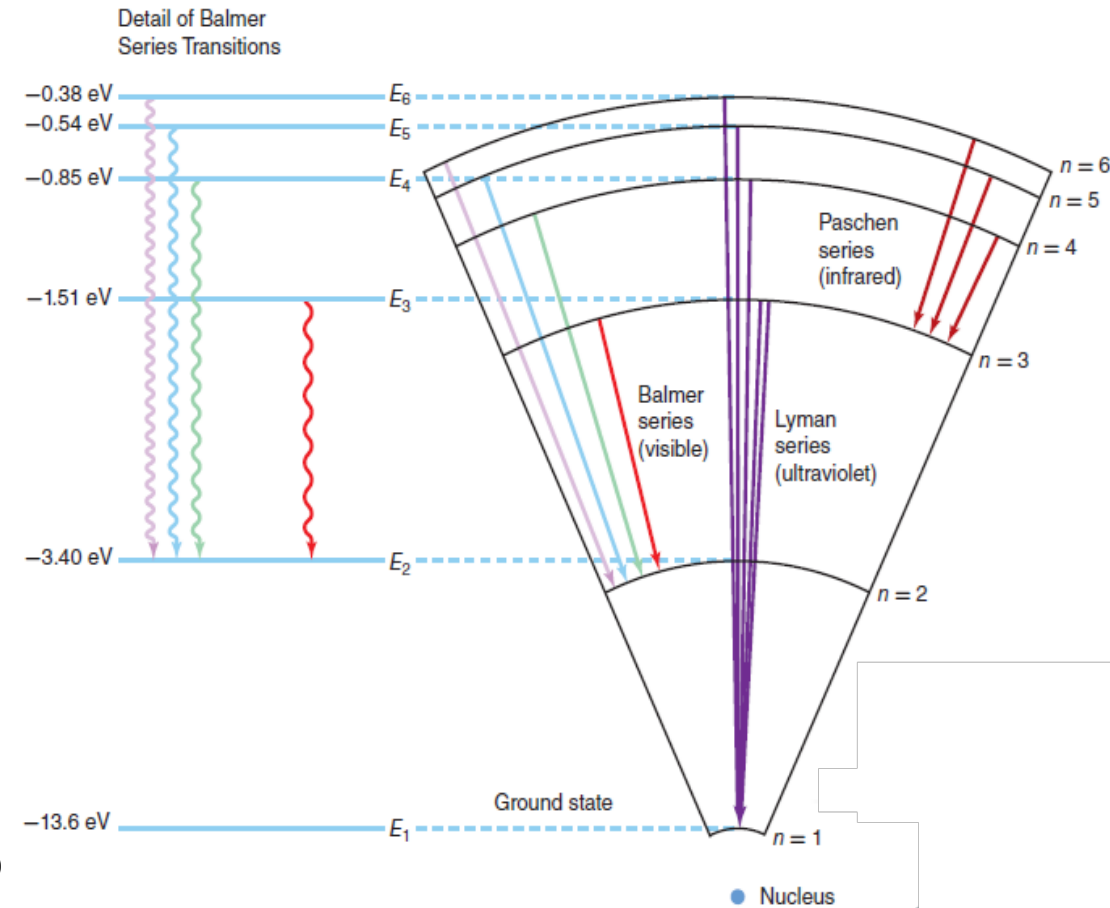
The four visible lines in the hydrogen spectrum are produced when the atom drops from the $n = 3$ or higher energy state into the $n = 2$ energy state

$$n = 3, 4, 5 \dots \text{to } n = 2$$

Paschen series

Infrared radiation is emitted when the atom drops from the $n = 4$ or higher energy state into the $n = 3$ energy state.

$$n = 4, 5, 6 \dots \text{to } n = 3$$





LO:

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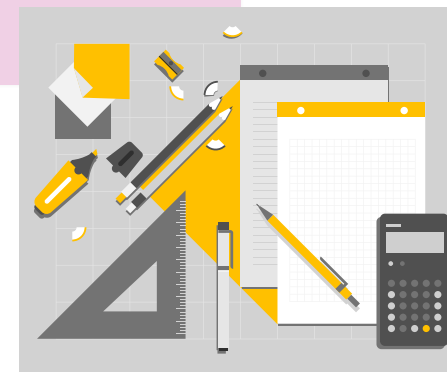
Illustrate that, in the Bohr model, the circumference of a stable electron orbit must be an integer multiple of the de Broglie wavelength ($2\pi r = n\lambda$), as a result of combining de Broglie and Bohr ideas.



Example
/
Exercise

St. textbook

P- 95





De Broglie waves in the atom:

de Broglie proposed that particles have wave properties.

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

The de Broglie wavelength of a particle with a momentum (mv)

$$mvr = \frac{hr}{\lambda}$$

The angular momentum of a particle

$$mvr = \frac{nh}{2\pi}$$

Bohr's required quantized angular-momentum condition.

$$\frac{nh}{2\pi} = \frac{hr}{\lambda}$$

$$2\pi r = n\lambda$$

The circumference of the Bohr orbit ($2\pi r$) must be equal to a whole number multiple (n) of de Broglie wavelengths (λ).

■ de Broglie waves

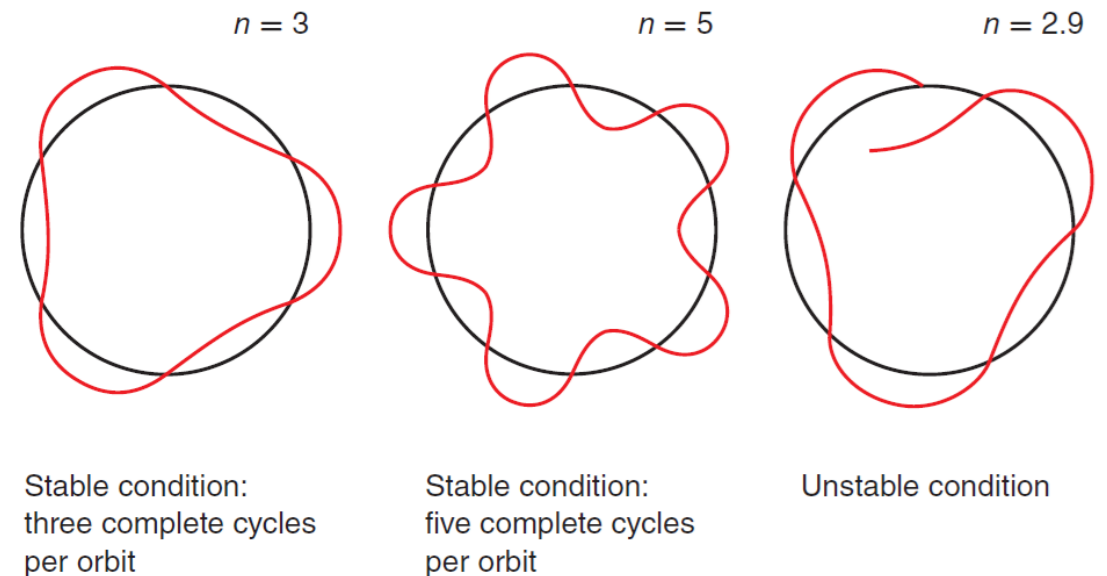


Figure 13 In the Bohr model of the atom, stable electron orbits around the nucleus must have a circumference equal to a whole-number multiple (n) of the de Broglie wavelengths.



Extra questions

3. The diagram shows a de Broglie wavelength of an electron in a hydrogen atom. Using the diagram answer the following questions:

a. In which energy level is the electron located?

The diagrams shows (4) complete waves which indicate that the electron is in the fourth energy level.

b. Calculate the radius of the orbit in which the electron is located?

$$r_n = \frac{h^2 n^2}{4\pi^2 k m_e e^2}$$

$$r_4 = \frac{(6.63 \times 10^{-34})^2 (4)^2}{4\pi^2 (9 \times 10^9) (9.11 \times 10^{-31}) (1.6 \times 10^{-19})^2}$$

$$r_4 = 8.5 \times 10^{-10} m$$

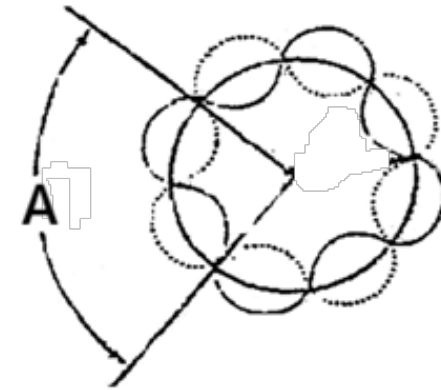
c. Calculate the angular momentum of this electron?

$$mvr = \frac{nh}{2\pi}$$

$$mvr = \frac{(4)(6.63 \times 10^{-34})}{2\pi} = 4.22 \times 10^{-34} \frac{kg \cdot m^2}{s}$$

b. What does (A) represents?

A wavelength





Extra questions

4. Why is the orbit with $n = 3$ is stable?

A. The electron moves faster

B. The wave fits exactly into the orbit circumference

C. The nucleus attracts the electron more

D. The wavelength is zero

5. What condition must be satisfied for a stable orbit?

A. $2\pi r = \lambda$

B. $2\pi r = n\lambda$

C. $r = n\lambda$

D. $\lambda = nr^2$

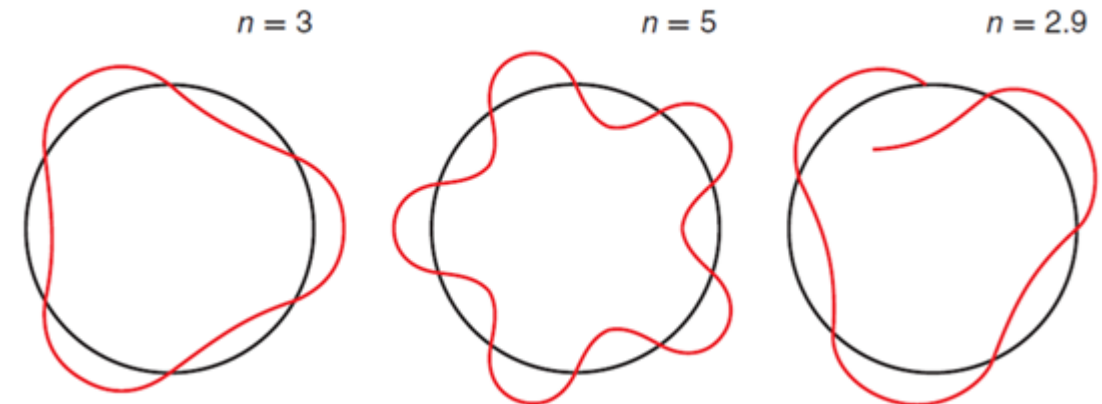
6. Why is the case $n = 2.9$ is unstable?

A. The electron stops moving

B. The wavelength is too large

C. The wave does not form a closed standing wave

D. The nucleus repels the electron





Extra questions

7. What happens when the wave does not fit exactly around the orbit?

A. The electron becomes stationary

B. The wave interferes destructively and becomes unstable

C. The electron gains energy

D. The orbit becomes circular

8. What does increase n (e.g., from 3 to 5) represent?

A. Decreasing energy level

B. Fewer wave cycles

C. More complete wavelengths fitting in the orbit

D. Electron moves closer to nucleus





LO:

18

Define the mass number, A , as the total number of nucleons (protons and neutrons) in an atomic nucleus ($A = Z + N$).

Represent nuclei of isotopes using the notation, where ' Z ' is the atomic number and ' A ' is the mass number

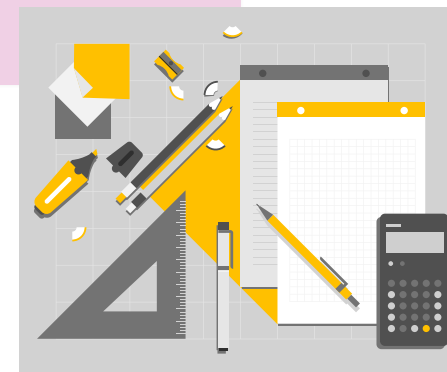


Example
/
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Describing the nucleus:



Nucleons:

The total number of protons and neutrons in an atom's nucleus.

Atomic number (Z):

The number of protons in an atom.

Used to find the charge of the nucleus, multiply this number by the elementary charge (e).

$$(Q = +Ze)$$

a nucleus with five protons
has a charge of +5e.

Mass number (A):

The number of nucleons (protons and neutrons) in an atom.

Protons and neutrons have almost the same mass—approximately $(1.66 \times 10^{-27} \text{ kg})$.

$$(A = Z + N)$$

Atomic mass unit (**u**): the mass of 1 proton

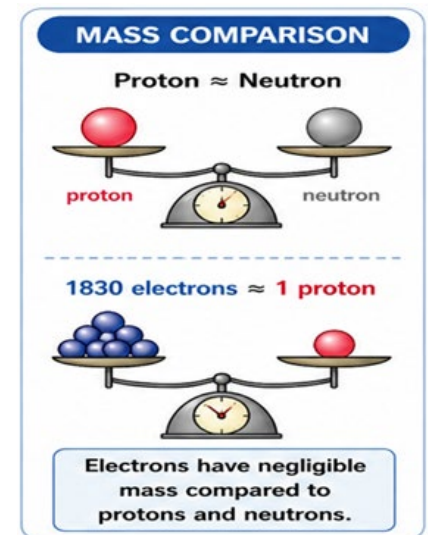
$$\text{approximate nuclear mass} = A \times u$$



X = element symbol

A = mass number

Z = atomic number



**PRACTICE PROBLEMS** (page 109)

1. Three isotopes of uranium have mass numbers of 234, 235, and 238. The atomic number of uranium is 92. How many neutrons are in the nucleus of each isotope?

$$A = Z + N$$

$$N = A - Z$$

$${}_{92}^{234}\text{U} \quad N = 234 - 92 = 142$$

$${}_{92}^{235}\text{U} \quad N = 235 - 92 = 143$$

$${}_{92}^{238}\text{U} \quad N = 238 - 92 = 146$$

2. How many neutrons are in an atom of the mercury isotope ${}_{80}^{200}\text{Hg}$?

$${}_{80}^{200}\text{Hg} \quad N = 200 - 80 = 120$$



**PRACTICE PROBLEMS** (page 109)

3. An isotope of oxygen has a mass number of 15. How many neutrons are in a nucleus of this isotope?

$${}^{15}_{6}\text{O} \quad N = 15 - 6 = 7$$

4. **CHALLENGE** Write the symbols for the three isotopes of hydrogen that have zero, one, and two neutrons in the nucleus.





Extra questions

1. Write the subatomic particles numbers of Aluminum, using the notation below:



A- Atomic number= 13

B- Mass number = 27

C- Nucleon number= 27

D- Number of protons= 13

E- Number of electrons= 13

F- Number of neutrons= 27 - 13 = 14

2. A nucleus X has 17 protons and 18 neutrons.
Which notation is correct for this nucleus?

A- ${}_{18}^{17}\text{X}$

B- ${}_{35}^{17}\text{X}$

C- ${}_{17}^{18}\text{X}$

D- ${}_{17}^{35}\text{X}$





Extra questions

3. The atomic number of a given element is equivalent to which of the following?

A) Proton number in the nucleus

B) Neutron number in the nucleus

C) Number of electrons in the outer shell

D) Sum of protons and neutrons

4. Which term refers to the total number of protons and neutrons in a nucleus?

A) Atomic number

B) Electron number

C) Nucleon number

D) Avogadro's number

5. A neutral atom is designated by ${}^{40}_{18}\text{X}$.

Complete the table below with the number of protons, neutrons, electrons, and nucleons this neutral atom has.

Number of Protons	18
Number of Neutrons	$40 - 18 = 22$
Number of Electrons	18
Number of Nucleons	40





LO:

19

Define the strong nuclear force as a very short-range attractive force that acts between nucleons (proton-proton, neutron-neutron, and proton-neutron) when they are very close together, as in the atomic nucleus.

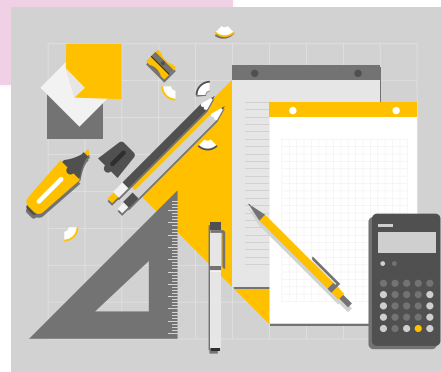
Define the mass defect as the difference between the actual mass of an atomic nucleus and the sum of the masses of its constituting nucleons.



Example
/
Exercise

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P- 109



Nuclear force:



What is the charge of each of the following?

Electron:  Negative

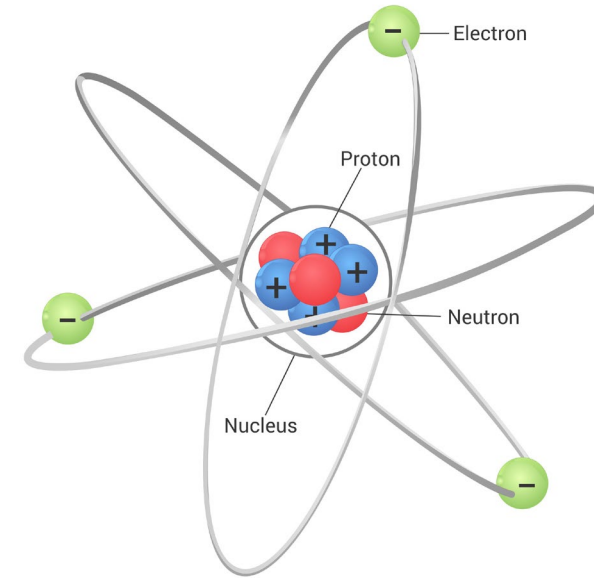
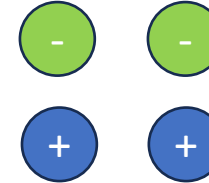
Proton:  Positive

Neutron:  No charge

Attract



Repel



The **negatively charged** electrons around the **positively charged** nucleus of an atom are held in place by **the attractive** electromagnetic force.



The nucleus consists of positively charged protons and neutral neutrons. The protons repel each other. Why don't the protons cause the nucleus to fly apart?

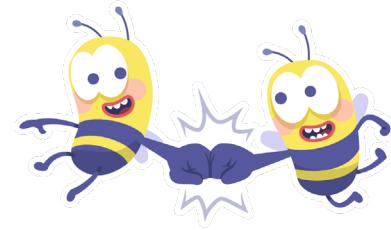


The strong nuclear force:



The protons in the nucleus repel each other but still the **nucleus is stable**, what do you conclude from that?

There must be a stronger attractive force exists within the nucleus.



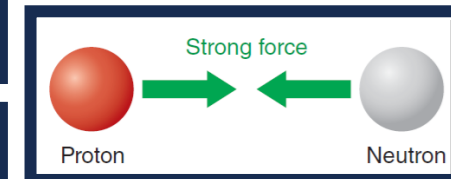
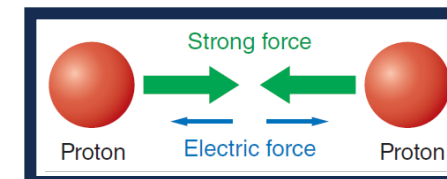
The strong nuclear force, also called the strong force, is an **attractive force** between **nucleons** that are close together, as they are in a nucleus.

Short range force.

When any pair of nucleons gets within about a proton's radius ($1.4 \times 10^{-15}m$) of each other, they experience an attraction that is more than **100 times stronger** than the electromagnetic force.

Affect all nucleon.

The strong force has the same strength between all nucleon pairs (proton-proton, neutron-neutron, or proton-neutron).





Check Your Progress (page 112)

13. Strong Nuclear Force The range of the strong nuclear force is so short that only nucleons that are adjacent to each other are affected by the force. Use this fact to explain why, in large nuclei, the repulsive electromagnetic force can overcome the strong attractive force and make the nucleus unstable.

The electric force is long range, so that all protons repel each other, even in large nuclei.

The strong force is short range, so that only neighboring protons attract.

The repulsive force grows, with increasing nuclear size, faster than the strong force.





Extra questions

1. What is the nature of the nuclear force between nucleons?

A) Long-ranged and weak

B) Short-ranged and strong

C) Long-ranged and repulsive

D) Short-ranged and repulsive

2. Why do stable nuclei exist despite the repulsive Coulomb force between protons?

Because the **strong nuclear force** acts between nucleons (protons and neutrons).

It is **much stronger than the electrostatic repulsion** at very short distances and holds the nucleus together.





Extra questions

3. What force inside a nucleus acts to push the nucleus apart?

The repulsive electric force between the positive protons acts to push the nucleus apart.

What force inside the nucleus acts to hold the nucleus together?

The strong nuclear force acts to hold the nucleus together.



Mass defect and binding energy:



Let's consider a helium nucleus (${}^4_2\text{He}$).

What is the number of protons in this nucleus?

2

What is the number of neutrons in this nucleus?

2



What is the expected mass of the nucleus?

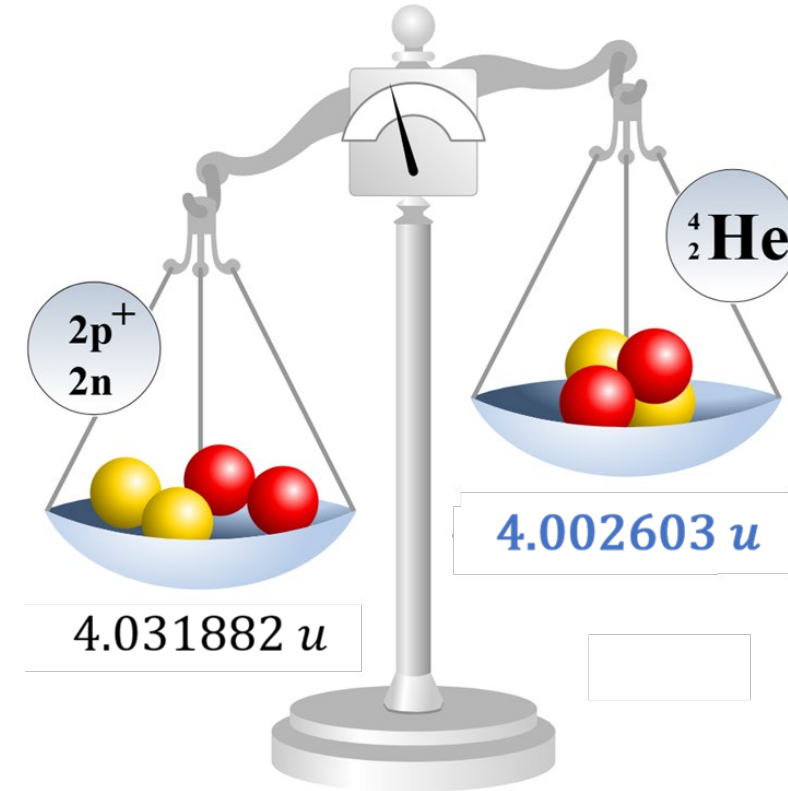
The mass of a proton is 1.007276 u.

The mass of a neutron is 1.008665 u.



$$\text{mass of } ({}^4_2\text{He}) = 2(1.007276 \text{ u}) + 2(1.008665 \text{ u})$$

$$\text{mass of } ({}^4_2\text{He}) = 4.031882 \text{ u}$$



Careful measurement shows the mass of a helium nucleus is only 4.002603 u.

The actual mass of the helium nucleus is less than the mass of its constituent parts by 0.029279 u.





Mass defect and binding energy:



This difference between the sum of the masses of the individual nucleons and the actual mass is called the **mass defect**.

Why is there a mass defect?

Mass can be converted to energy

Einstein's famous equation.

$$E = mc^2$$

E: energy

m: mass

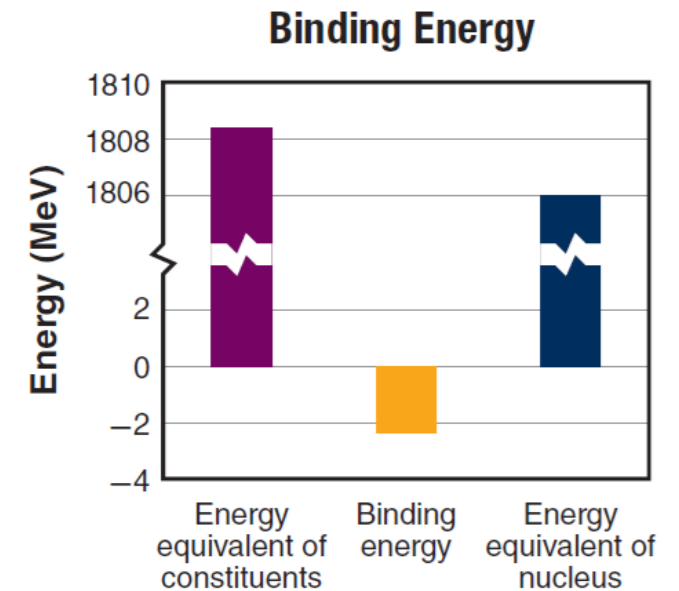
*c*²: speed of light



Mass defect and binding energy:



- Mass and energy are the same.
- To pull a nucleon out of a nucleus, you have to do work to overcome the strong nuclear force.
- Doing work adds energy to the system. Thus, the system of separated protons and neutrons has more energy than the assembled nucleus.
- This energy difference between separated nucleons and the assembled nucleus is the **binding energy** of the nucleus.
- Because the assembled nucleus has less energy, all binding energies are negative, as shown in **Figure 5**.
- The binding energy can be expressed in the form of an equivalent amount of mass, according to Einstein's famous equation.



$$E = mc^2$$



Get It?

Explain What binding energy is?

This energy difference between separated nucleons and the assembled nucleus





Extra questions

4. What is the mass defect of a nucleus?

- A. The mass lost due to electron capture
- B. The additional mass gained during nuclear fusion
- C. The difference in mass between an atom and its nucleus

D. The difference between the total mass of the individual nucleons and the actual mass of the nucleus

5. What happens to the missing mass in a nucleus due to the mass defect?

- A. It is lost in the form of heat
- B. It is converted into extra protons
- C. It is absorbed by electrons to form stable atoms

D. It is converted into binding energy that holds the nucleus together





Extra questions

6. The mass of the nucleus is less than the total mass of its nucleons. This indicates that some of the mass has been converted to _____.

A. thermal energy

B. binding energy

C. kinetic energy

D. potential energy

7. Which statement best explains why the mass defect occurs?

A. Some mass is converted into energy when the nucleus is formed.

B. The mass of protons is always greater than the mass of neutrons.

C. Some electrons escape from the nucleus, causing a loss in mass.

D. The binding energy reduces the size of the nucleus, making it appear less massive.





Extra questions

16. Are the sentences below **True** or **False** and **explain** your answer:

a. The total mass of a nucleus is always less than the sum of the masses of its nucleons.



True



Due to **mass defect** (some mass is converted to binding energy).

b. The total energy of the bound system (the nucleus) is more than the combined energy of the separated nucleons.



False



The nucleus has **lower energy** (more stable). Energy was released when it formed.

c. Binding energy is the energy given out when the separate nucleons combine to form the nucleus.



True



This is the energy released during formation.

d. Binding energy is the energy required for a nucleus to break it apart into its separated neutrons and protons.



True



Same energy but viewed in reverse (energy needed to break the nucleus).





LO:

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Calculate the mass defect of an atomic nucleus.

Calculate the binding energy of an atomic nucleus.



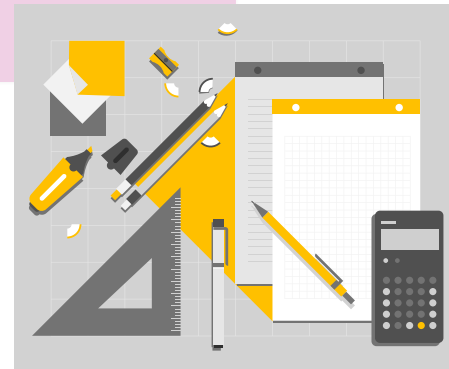
Example
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Example problem 1

Practice problems

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Determining the mass defect:



Mass defect (Δm): is the difference between an atomic nucleus's actual mass and the sum of the individual masses of its constituent protons and neutrons.

$$\Delta m = \text{mass of nucleus} - [\text{mass of All } P + \text{mass of All } N]$$

$$\Delta m = m_{\text{nucleus}} - [(N_p \times m_p) + (N_n \times m_n)]$$

(Δm) then can be used to calculate the binding energy according to Einstein's famous equation.

$$E = \Delta mc^2$$

(E) Energy in (J)

(Δm) Mass in (Kg)

(N_p) number of protons

(N_n) number of neutrons

(m_p) mass of protons

(m_n) mass of neutrons

(m_{nucleus}) mass of nucleus

Mass spectrometers usually measure the masses of isotopes; that is, they measure the mass of the nucleus and the electrons.

Masses are usually measured in **atomic mass units**.

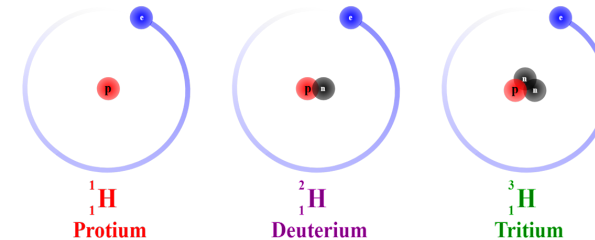
In this calculation, each quantity will be expressed with **five significant digits**.



**Example problem** (page 111)

MASS DEFECT AND BINDING ENERGY Find the mass defect and binding energy of tritium (${}^3_1\text{H}$). The mass of the tritium isotope is 3.016049 u , the mass of a hydrogen atom is 1.007825 u , and the mass of a neutron is 1.008665 u .

Tritium (${}^3_1\text{H}$) is equivalent to: $\left\{ \begin{array}{l} {}^1_1\text{H} \text{ One hydrogen atom} \\ 2N \text{ Two neutrons} \end{array} \right.$

Mass of tritium parts:

$$m_{\text{tritium-parts}} = m_{\text{hydrogen}} + 2m_{\text{neutron}}$$

$$m_{\text{tritium-parts}} = 1.007825 \text{ u} + 2(1.008665) \text{ u} = 3.025155 \text{ u}$$

Mass defect:

$$\Delta m = m_{\text{tritium}} - m_{\text{tritium-parts}}$$

$$\Delta m = 3.016049 \text{ u} - 3.025155 \text{ u} = -0.009106 \text{ u}$$

Binding energy of tritium :

$$E = \Delta m \times (931.49 \text{ MeV/u})$$

$$E = (-0.009106 \text{ u}) \times (931.49 \text{ MeV/u})$$

$$E = -8.4821 \text{ MeV}$$



**PRACTICE PROBLEMS** (page 111)

5. The carbon isotope $^{12}_6\text{C}$ has a mass of 12.000 u.

a. Calculate its mass defect.

$$\Delta m = m_{\text{nucleus}} - [(N_p \times m_p) + (N_n \times m_n)]$$

$$\Delta m = 12.0000 - [(6 \times 1.007825) + (6 \times 1.008665)]$$

$$\Delta m = -0.098940 \text{ u}$$

b. Calculate its binding energy.

$$E = \Delta m \times (931.49 \text{ MeV/u})$$

$$E = (-0.098940 \text{ u}) \times (931.49 \text{ MeV/u})$$

$$E = -92.161 \text{ MeV}$$

mass of hydrogen = 1.007825 u
mass of neutron = 1.008665 u
1 u = 931.49 MeV

6. Deuterium ^2_1H has a mass of 2.014102 u.

a. Calculate its mass defect.

$$\Delta m = m_{\text{nucleus}} - [(N_p \times m_p) + (N_n \times m_n)]$$

$$\Delta m = 2.014102 - [(1 \times 1.007825) + (1 \times 1.008665)]$$

$$\Delta m = -0.002388 \text{ u}$$

b. Calculate its binding energy.

$$E = \Delta m \times (931.49 \text{ MeV/u})$$

$$E = (-0.002388 \text{ u}) \times (931.49 \text{ MeV/u})$$

$$E = -2.2244 \text{ MeV}$$



**PRACTICE PROBLEMS** (page 111)

7. The nitrogen isotope $^{15}_7\text{N}$ has a mass defect of -0.113986 u .

a. Calculate the mass of this isotope.

$$\Delta m = m_{\text{nitrogen}} - [(N_p \times m_p) + (N_n \times m_n)]$$

$$m_{\text{nitrogen}} = -0.113986 - [(7 \times 1.007825) + (8 \times 1.008665)]$$

$$m_{\text{nitrogen}} = 15.010109 \text{ u}$$

b. Calculate the binding energy of the nucleus.

$$E = \Delta m \times (931.49 \text{ MeV/u})$$

$$E = (-0.113986 \text{ u}) \times (931.49 \text{ MeV/u})$$

$$E = -106.18 \text{ MeV}$$



**PRACTICE PROBLEMS** (page 111)

6. 8. CHALLENGE The oxygen isotope $^{16}_8\text{O}$ has a mass of 15.994915 u. A second oxygen isotope is $^{18}_8\text{O}$, which has a mass of 17.999160 u.

a. What is the mass defect of each isotope?

$$\Delta m = m_{\text{nucleus}} - [(N_p \times m_p) + (N_n \times m_n)]$$

$$\Delta m = 15.994915 - [(8 \times 1.007825) + (8 \times 1.008665)]$$

$$\Delta m = -0.137005 \text{ u}$$

$$\Delta m = m_{\text{nucleus}} - [(N_p \times m_p) + (N_n \times m_n)]$$

$$\Delta m = 17.999160 - [(8 \times 1.007825) + (9 \times 1.008665)]$$

$$\Delta m = -0.148410 \text{ u}$$

b. What is the binding energy of each nucleus?

$$E = \Delta m \times (931.49 \text{ MeV/u})$$

$$E = (-0.137005 \text{ u}) \times (931.49 \text{ MeV/u}) = -127.62 \text{ MeV}$$

$$E = \Delta m \times (931.49 \text{ MeV/u})$$

$$E = (-0.148410 \text{ u}) \times (931.49 \text{ MeV/u}) = -138.24 \text{ MeV}$$

c. Why do you think the binding energies are different?

The nucleus of $^{18}_8\text{O}$ has more nucleons than $^{16}_8\text{O}$ and therefore experiences a larger strong force. Thus, $^{18}_8\text{O}$ is more tightly bound and has a more negative binding energy. Both $^{16}_8\text{O}$ and $^{18}_8\text{O}$ have eight protons and 88 experience the same repulsive electromagnetic force.





LO:

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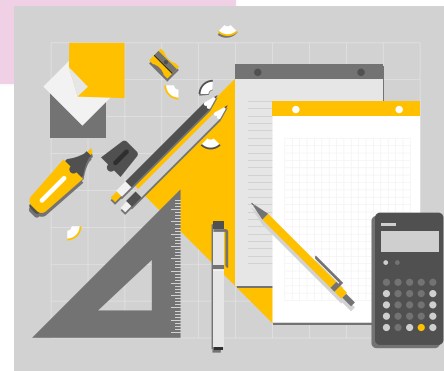
Compare alpha, beta, and gamma decays in terms of the particles emitted their electric charge, their penetrating ability, and the resulting nuclear transmutation



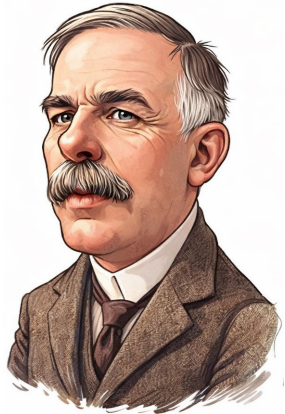
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Radioactive Decay:



Ernest Rutherford

In 1909, after years of experiments, Ernest Rutherford was able to identify the radiation that Becquerel had found.

Rutherford's team found that uranium compounds produce **three** kinds of radiation.

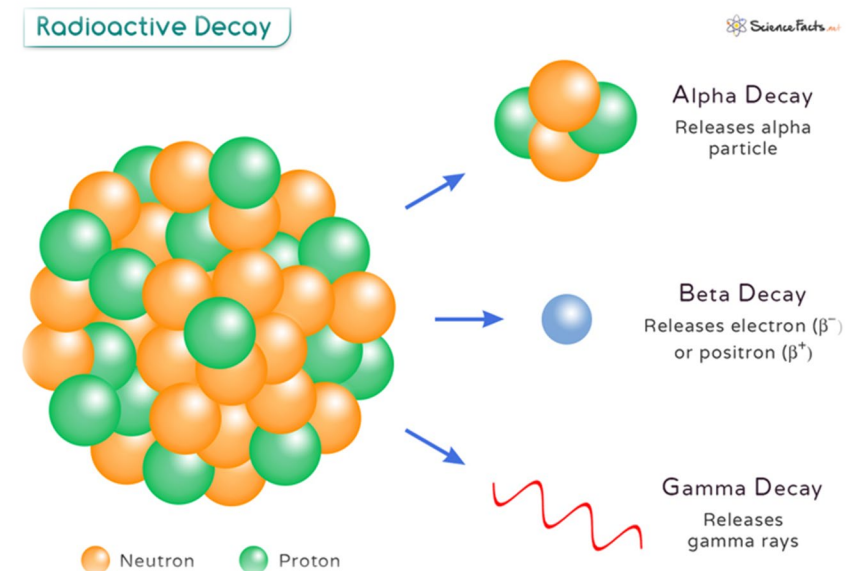
- (alpha α – particles)
- (beta β – particles)
- (gamma γ – rays)

Nuclei that emit particles and energy are said to be **radioactive**.

A material that emits particles is also said to **decay**.

Nuclei **decay** in order to become more **stable**.

Radioactive decay is a **natural** process.





Radioactive Decay:

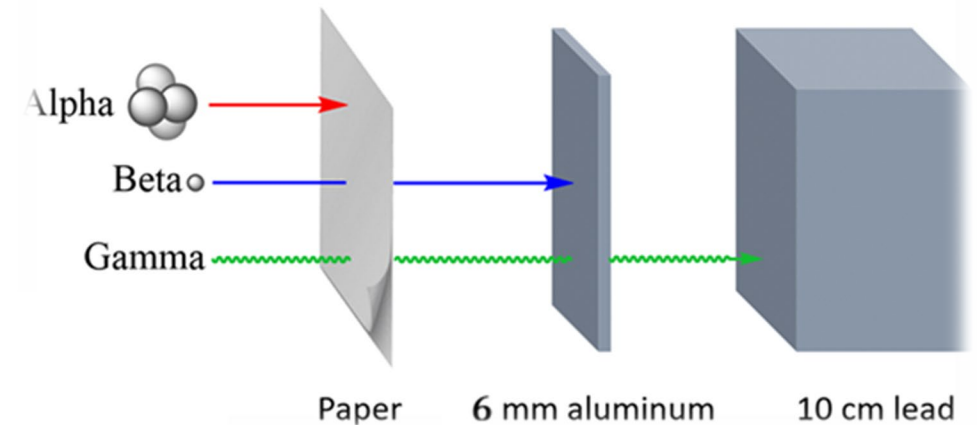


alpha (α), beta (β), and gamma (γ) radiation. Are classified by how easy it was to be stopped.



- A thick sheet of paper can stop alpha radiation.
- A 6 mm of aluminum can stop most beta radiation.
- Gamma rays are stopped by several centimeters of lead.

The Penetrating Power of Radioactive Decay Particles



Types of Radiation:



Alpha (α) decay	${}_Z^AX \rightarrow {}_{Z-2}^{A-4}Y + {}_2^4He$	least penetration charge +2	Parent → Daughter Alpha Particle	$A \rightarrow A - 4$ $Z \rightarrow Z - 2$ $N \rightarrow N - 2$
Beta ($-$) decay (${}_{-1}^0\beta$)	${}_Z^AX \rightarrow {}_{Z+1}^AY + {}_{-1}^0e + \bar{\nu}$	medium penetration charge -1	Parent → Daughter Beta Particle	$A \rightarrow A$ $Z \rightarrow Z + 1$ $N \rightarrow N - 1$
Beta ($+$) decay (${}_{+1}^0\beta$)	${}_Z^AX \rightarrow {}_{Z-1}^AY + {}_{+1}^0e + \nu$	medium penetration charge +1	Parent → Daughter Positron	$A \rightarrow A$ $Z \rightarrow Z - 1$ $N \rightarrow N + 1$
Gamma (γ) decay	${}_Z^AX^* \rightarrow {}_Z^AY + {}_0^0\gamma$	highest penetration no charge	Parent (excited nuclear state) → Daughter Gamma ray	$A \rightarrow A$ $Z \rightarrow Z$ $N \rightarrow N$



- Radioactive elements often go through a series of successive decays until they form a stable nucleus. For example, ${}_{92}^{238}U$ undergoes 14 separate decays before the stable lead isotope ${}_{82}^{206}Pb$ is produced.



Extra questions

1. **Radiation** What are the common names for an α particle, β particle, and γ radiation?

- α particle is a helium nucleus
- β particle is an electron or positron
- γ radiation is a high-energy photon.





LO:

22

Explain that electric charge is conserved in a nuclear reaction, so the total charge is the same on both sides of the nuclear equation



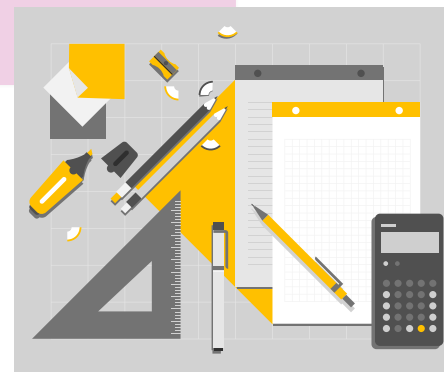
Example
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Example problem 2

Practice problems

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Extra questions

2. What two quantities must always be conserved in any nuclear equation?

- The atomic number, to conserve charge;
- The mass number, to conserve the number of nucleons



**Example problem 2** (page 116)

ALPHA AND BETA DECAY Write the nuclear equation for each radioactive process.

a. The radioactive radium isotope $^{226}_{88}\text{Ra}$ emits an α particle and becomes the radon isotope $^{222}_{86}\text{Rn}$.

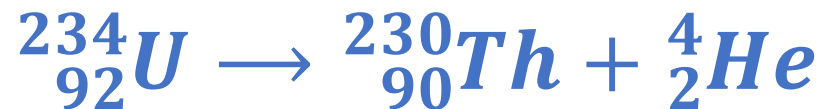


b. The radioactive lead isotope $^{209}_{86}\text{Pb}$ decays into the bismuth isotope $^{209}_{83}\text{Bi}$ by the emission of a β particle and an antineutrino.



**PRACTICE PROBLEMS** (page 116)

15. Write a nuclear equation for the transmutation of the radioactive uranium isotope ${}^{234}_{92}\text{U}$ into the thorium isotope ${}^{230}_{90}\text{Th}$ by the emission of an α particle.



16. Write a nuclear equation for the transmutation of the radioactive thorium isotope ${}^{230}_{90}\text{Th}$ into the radioactive radium isotope ${}^{226}_{88}\text{Ra}$ by the emission of an α particle.



17. Write a nuclear equation for the transmutation of americium ${}^{241}_{95}\text{Am}$ to neptunium ${}^{237}_{93}\text{Np}$ by the emission of an α particle.



18. Write a nuclear equation for the transmutation of the radioactive radium isotope ${}^{226}_{88}\text{Ra}$ into the radon isotope ${}^{222}_{86}\text{Rn}$ by α decay.



**PRACTICE PROBLEMS** (page 116)

19. The radioactive lead isotope $^{214}_{82}\text{Pb}$ can change to the radioactive bismuth isotope $^{214}_{83}\text{Bi}$ by the emission of a β particle and an antineutrino. Write the nuclear equation.



20. Challenge The radioactive carbon isotope $^{14}_6\text{C}$ undergoes β decay. Determine the product of the decay and write the nuclear equation.





Extra questions

2. Complete each nuclear reaction.

A- ${}_{88}^{222}\text{Ra} \rightarrow \underline{{}_{89}^{222}\text{X}} + \underline{{}_{-1}^0\beta} + \underline{\bar{\nu}}$

B- ${}_{18}^{40}\text{Ar} \rightarrow \underline{{}_{16}^{36}\text{X}} + \underline{{}_2^4\alpha}$

C- ${}_0^1n \rightarrow \underline{{}_1^1\text{P}} + \underline{{}_{-1}^0e} + \bar{\nu}$

D- ${}_{92}^{238}\text{U} \rightarrow \underline{{}_{90}^{234}\text{X}} + \underline{{}_2^4\alpha}$

E- ${}_{19}^{40}\text{K} \rightarrow \underline{{}_{18}^{40}\text{X}} + \underline{{}_{+1}^0e} + \underline{\nu}$

F- $\underline{{}_7^{13}\text{X}} \rightarrow \underline{{}_6^{13}\text{C}} + \underline{{}_{+1}^0e} + \nu$

G- $\underline{{}_{29}^{60}\text{X}} \rightarrow \underline{{}_{30}^{60}\text{Ni}} + \underline{{}_{-1}^0e} + \bar{\nu}$

H- $\underline{{}_1^1\text{P}} \rightarrow \underline{{}_0^1n} + \underline{{}_{+1}^0e} + \underline{\nu}$





LO:

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Write a balanced nuclear equation to describe a simple nuclear reaction, such as the bombardment of a nucleus by an alpha particle



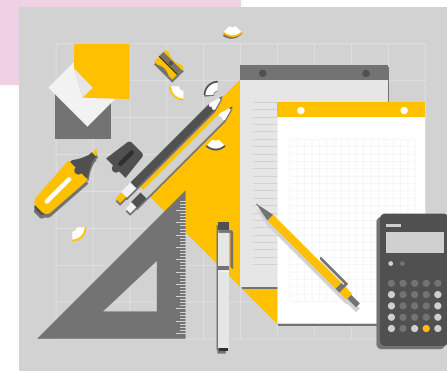
Example
/
Exercise

Example problem 3

Practice problems

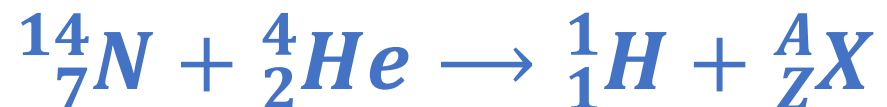
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**Example problem 3** (page 117)

SOLVE NUCLEAR EQUATIONS When **nitrogen** ${}^{14}_7\text{N}$ gas is bombarded with α particles, high-energy **protons** are emitted. What new isotope is created? Use the periodic table at the back of the book.



To find A and Z for the new element:

The atomic number, to conserve charge.

$$Z = 2 + 7 - 1 = 8$$

The mass number, to conserve the number of nucleons

$$A = 4 + 14 - 1 = 17$$

The element with $Z = 8$ is oxygen. The isotope must be ${}^{17}_8\text{O}$



**PRACTICE PROBLEMS** (page 117)

21. Use the periodic table at the back of your book to complete the following:



22. Write the nuclear equation for the transmutation of the seaborgium isotope ${}_{106}^{263}\text{Sg}$ into the rutherfordium isotope ${}_{104}^{259}\text{Rf}$ by the emission of an **alpha** particle.



**PRACTICE PROBLEMS** (page 117)

23. A **proton** collides with the nitrogen isotope $^{15}_7\text{N}$, forming a new isotope and an **alpha** particle. What is the isotope? Write the nuclear equation.



24. CHALLENGE Write the nuclear equations for the beta decay of the following isotopes:

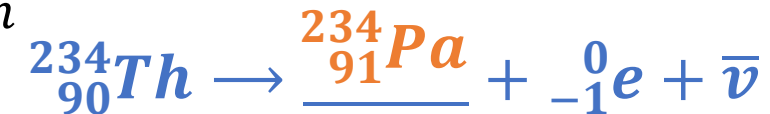
A- $^{210}_{82}\text{Pb}$



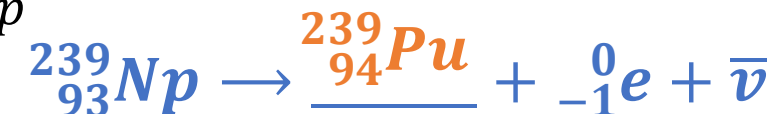
B- $^{210}_{83}\text{Bi}$



C- $^{234}_{90}\text{Th}$



D- $^{239}_{93}\text{Np}$





LO:

24

Analyze a graph of the number of undecayed radioactive nuclei versus time, and determine the half-life and the amount of radioactive nuclei present at a certain time t

Calculate the amount of radioactive nuclei remaining in a sample



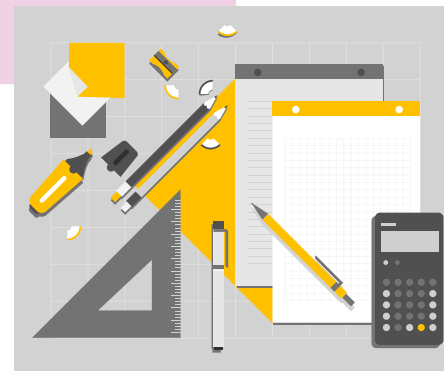
Example
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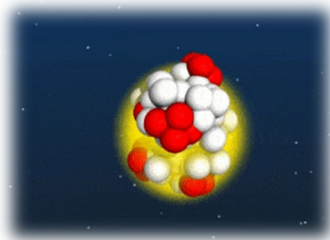




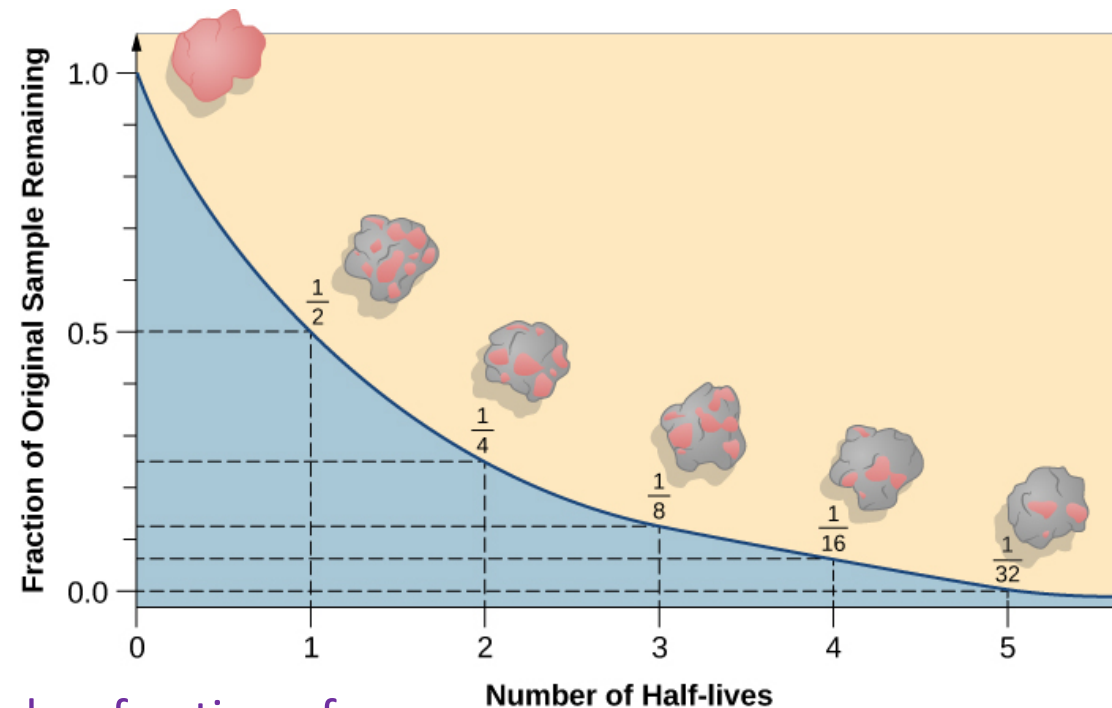
Half-Life:



What happens to a radioactive isotopes when it starts to decay:



Its unstable nucleus loses energy by emitting radiation to become more stable. This process transforms the original atom into a different isotope or an entirely new element



- Radioactive isotopes vary greatly in stability. Some exist for only a fraction of a second before decaying, while others may exist for billions of years.

The **half-life** is the time required for half of the atoms in any given quantity of a radioactive isotope to decay.

After each half-life, approximately half the nuclei remain undecayed.



Half-Life:



How can we benefit from knowing the half-life time:

- Half-lives of radioactive isotopes are used to date objects.

The age of a sample of organic material can be found by measuring the amount of carbon-14 remaining. The age of Earth was calculated based on the decay of uranium into lead.

HALF-LIFE

The amount of a radioactive isotope remaining in a sample equals the original amount times $\frac{1}{2}$ to the t , where t is the number of half-lives that have passed.

$$\text{Remaining} = \text{Original} \left(\frac{1}{2} \right)^t$$

Activity: The number of decays per second of a radioactive substance.

Activity is proportional to the number of radioactive atoms present.

The activity of a sample also is reduced by one-half in one half-life.

Table 2 Half-Lives of Selected Isotopes

Element	Isotope	Half-Life
Hydrogen	^3_1H	12.3 years
Carbon	$^{14}_6\text{C}$	5730 years
Cobalt	$^{60}_{27}\text{Co}$	30 years
Iodine	$^{131}_{53}\text{I}$	8.07 days
Lead	$^{212}_{82}\text{Pb}$	10.6 hours
Polonium	$^{194}_{84}\text{Po}$	0.7 seconds
Polonium	$^{210}_{84}\text{Po}$	138 days
Uranium	$^{235}_{92}\text{U}$	7.1×10^8 years
Uranium	$^{238}_{92}\text{U}$	4.51×10^9 years
Plutonium	$^{236}_{94}\text{Pu}$	2.85 years
Plutonium	$^{242}_{94}\text{Pu}$	3.79×10^8 years

SI unit
Becquerel
(Bq).



**PRACTICE PROBLEMS** (page 119)

25. A 1.0-g sample of tritium (${}^3_1\text{H}$) is produced. After 24.6 years, what mass of tritium will remain?

half-life of ${}^3_1\text{H} = 12.3$ years

$$\text{Number of half-lives} = \frac{24.6}{12.3} = 2 \text{ half-lives}$$

$$\text{Remaining} = \text{Original} \left(\frac{1}{2}\right)^t$$

$$\text{Remaining} = (1) \left(\frac{1}{2}\right)^2 = 0.25 \text{ g}$$

26. The isotope (${}^{238}_{93}\text{Np}$) has a half-life of 2.0 days. If 4.0 g of neptunium is produced on Monday, what will be the mass of neptunium remaining on Tuesday of the next week?

half-life of ${}^{238}_{93}\text{Np} = 2$ days

From Monday to Tuesday of the next week we have (8 days)

$$\text{Number of half-lives} = \frac{8}{2} = 4 \text{ half-lives}$$

$$\text{Remaining} = \text{Original} \left(\frac{1}{2}\right)^t$$

$$\text{Remaining} = (4) \left(\frac{1}{2}\right)^4 = 0.25 \text{ g}$$



**PRACTICE PROBLEMS** (page 119)

27. A sample of ($^{210}_{84}\text{Po}$) is purchased on **September 1**. Its activity is $2 \times 10^6 \text{ Bq}$. The sample is used in an experiment on **June 1**. What activity can be expected?

half-life of $^{238}_{93}\text{Np} = 138 \text{ days}$

From **September 1** to **June 1**, we have ($\approx 273 \text{ days}$)

$$\text{Number of half-lives} = \frac{273}{138} = 2 \text{ half-lives}$$

$$\text{Remaining} = \text{Original} \left(\frac{1}{2} \right)^t$$

$$\text{Remaining} = (2 \times 10^6) \left(\frac{1}{2} \right)^2 = 5 \times 10^5 \text{ Bq}$$

28. CHALLENGE Tritium (^3_1H) once was used in watches to produce a fluorescent glow with a brightness proportional to tritium's activity. Compare the watch's brightness after **6 years** to its original brightness.

half-life of $^3_1\text{H} = 12.3 \text{ years}$

$$\text{Number of half-lives} = \frac{6}{12.3} = 0.487 \text{ half-lives}$$

$$\text{Remaining} = \text{Original} \left(\frac{1}{2} \right)^t$$

$$\text{Remaining} = \text{Original} \left(\frac{1}{2} \right)^{0.487} = 0.713 \text{ Original}$$



**Extra questions**

1. Half-Life Estimate in how many days a sample of ($^{131}_{53}\text{I}$) would have **three-eighths** its original activity.

half-life of $^{131}_{53}\text{I} = 8.07$ days

$$\text{Remaining} = \text{Original} \left(\frac{1}{2}\right)^t$$

$$\frac{3}{8} \text{ original} = \text{Original} \left(\frac{1}{2}\right)^t$$

$$\frac{3}{8} = \left(\frac{1}{2}\right)^t$$

$$t = \frac{\ln \frac{3}{8}}{\ln \frac{1}{2}}$$

$$\ln \frac{3}{8} = \ln \left(\frac{1}{2}\right)^t$$

$$t = 1.4 \text{ half lives}$$

$$\ln \frac{3}{8} = t \ln \frac{1}{2}$$

$$\text{number of days} = (1.4)(8.07) = 11.3 \text{ days}$$

2. An isotope has a half-life of **3.0 days**. What percent of the original material will be left after

a. 6.0 days.

$$\frac{6 \text{ d}}{3 \text{ d}} = 2 \text{ half lives}$$

$$\text{Remaining} = \text{Original} \left(\frac{1}{2}\right)^2 = 0.25 \text{ original}$$

B. 9.0 days.

$$\frac{9 \text{ d}}{3 \text{ d}} = 3 \text{ half lives}$$

$$\text{Remaining} = \text{Original} \left(\frac{1}{2}\right)^3 = 0.13 \text{ original}$$



**Extra questions**

3. In an accident in a research laboratory, a radioactive isotope with a half-life of **three days** is spilled. As a result, the radiation is **eight times** the **maximum permissible** amount. How long must workers wait before they can enter the room?

The activity must fall to (1/8) its present amount, to be safe

$$\frac{1}{8} \text{ original} = \text{Original} \left(\frac{1}{2} \right)^t$$

$$\frac{1}{8} = \left(\frac{1}{2} \right)^t \quad \left| \quad t = \frac{\ln \frac{1}{8}}{\ln \frac{1}{2}} \right.$$

$$\ln \frac{1}{8} = \ln \left(\frac{1}{2} \right)^t \quad \left| \quad t = 3 \text{ half lives} \right.$$

$$\ln \frac{1}{8} = t \ln \frac{1}{2} \quad \left| \quad \text{number of days} = (3)(3) = 9 \text{ days} \right.$$

4. ${}^{209}_{84}\text{Po}$ has a half-life of **103 years**. How long would it take for a **100-g** sample to decay so that only **3.1 g** of Po-209 was left?

$$\text{Remaining} = \text{Original} \left(\frac{1}{2} \right)^t$$

$$3.1 = 100 \left(\frac{1}{2} \right)^t$$

$$\frac{3.1}{100} = \left(\frac{1}{2} \right)^t$$

$$\ln \frac{3.1}{100} = t \ln \frac{1}{2}$$

$$t = \frac{\ln \frac{3.1}{100}}{\ln \frac{1}{2}} = 5 \text{ half lives}$$

$$\text{number of years} = (5)(103) = 515 \text{ y}$$





Extra questions

5. a 100 g radioactive isotope (X) with a half-life of 3 days and a 100 g radioactive isotope (Y) with a half-life of 6 days which one have the greater its activity?

Activity: is the number of decays per second of a radioactive substance.

The higher the **Activity** the shorter the half- lifetime the isotope will decay faster.

isotope (X) have the greater activity.





LO:

25

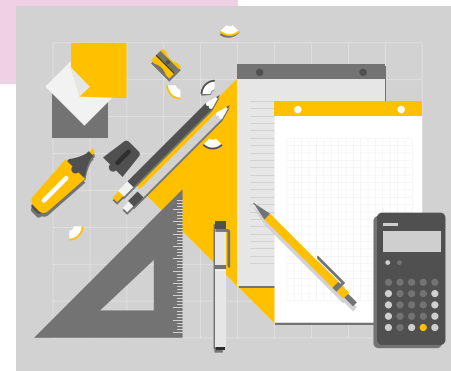
Define and describe nuclear fission and nuclear fusion



Example
/
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Nuclear Fission:



Artificial Radioactivity can release energy.

Scientists found out that the bombardment of a neutrons with uranium had caused a division of the uranium into two smaller nuclei, resulting in a large release of energy.

A lot of energy

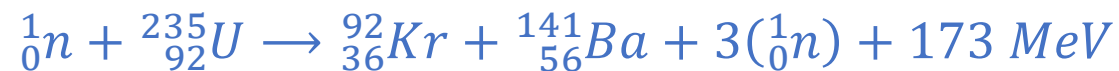


The possibility of a new source of energy



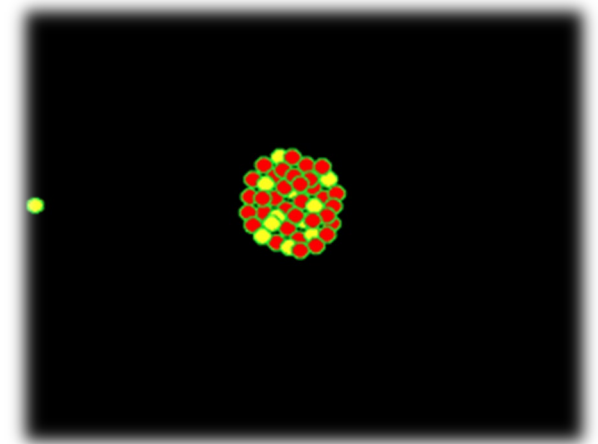
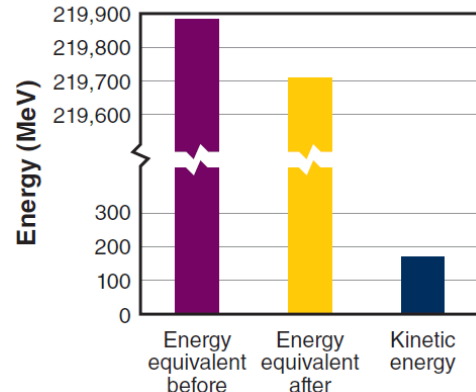
The division of a nucleus into two or more fragments is called **fission**.

Uranium isotope $^{235}_{92}\text{U}$ undergoes fission when it is bombarded with neutrons. The elements barium and krypton are typical results of this fission, as described by the following equation:



The energy released by each fission can be found by calculating the masses of the atoms on each side of the equation. In the reaction above, the total mass on the right side of the equation is 0.186 u smaller than that on the left. This energy appears as the kinetic energy of the products of the fission,

Energy in a Fission Reaction





Nuclear Fusion:



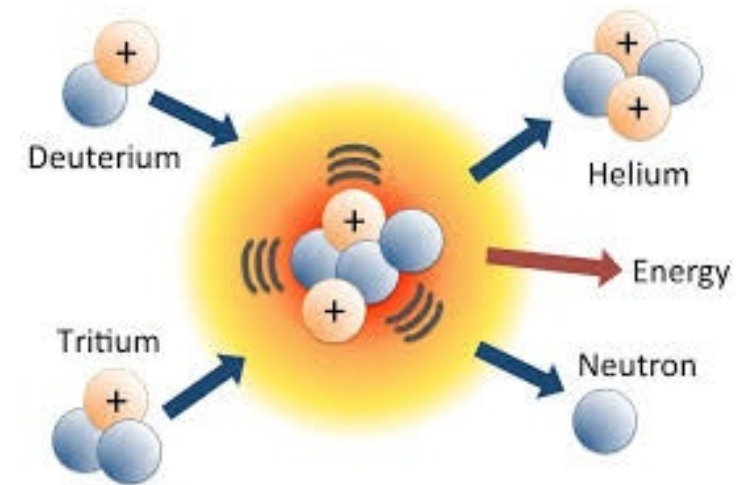
How does small nuclei become more stable?

Nuclear fusion: nuclei with small masses combine to form a nucleus with a larger mass.

In this process, energy is released.

larger nucleus is more tightly bound, so its mass is less than the sum of the masses of the smaller nuclei.

This loss of mass corresponds to a release of energy.



Nuclear Fusion:



Where does a nuclear fusion occur?

An example of fusion is a process that occurs in the Sun.

This process, called the **proton-proton** chain, is shown in the **Figure**.

Four hydrogen nuclei (protons) fuse in several steps to **form one helium nucleus**.

The proton-proton chain can be represented in equation form:



The net result (subtracting out the two protons produced in the final step) is that four protons produce **one (${}_2^4\text{He}$)**, **two positrons**, and **two neutrinos**.

