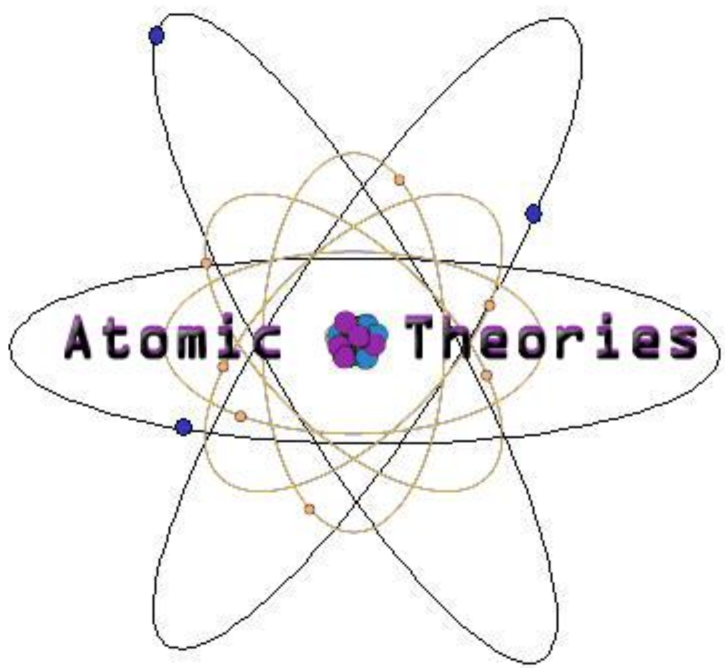
Early Atomic Theories and the Origins of Quantum Theory

Chapter 3.1

What is Matter Made of?

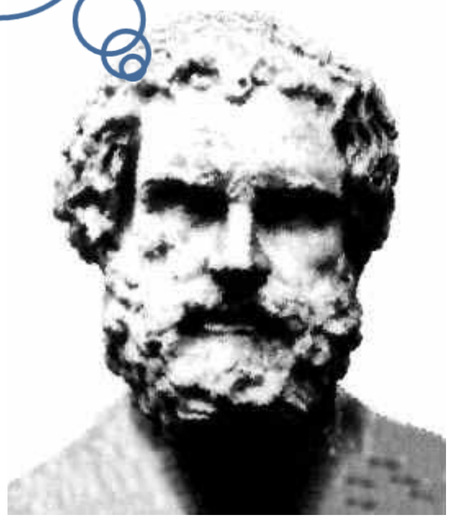
- People have wondered about the answer to this question for thousands of years



Philosophers

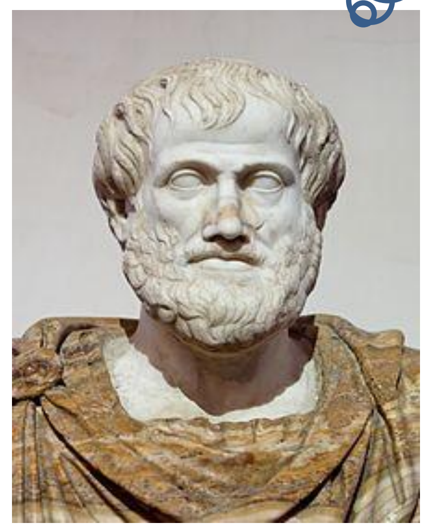
Matter is composed of tiny, indivisible particles called atoms

All matter is made of four elements: earth, air, fire, and water



Democritus

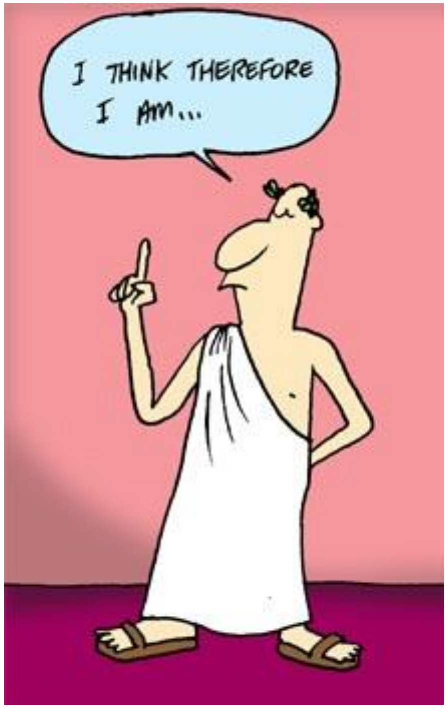
vs.



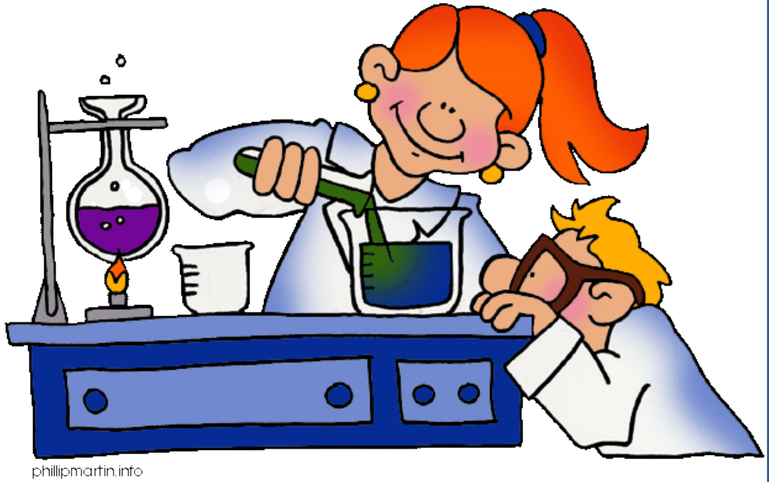
Aristotle

Philosophy and Science

- **Philosophers** come up with their ideas based on intuition and reason



- **Scientists** come up with their ideas through experimentation using tools and technology



John Dalton

Dalton's atomic theory was based on the experimental work of many other scientists who used instruments that were invented to precisely measure mass and volume:

1) **The Law of Conservation of Mass** – Antoine Lavoisier
   "Matter can not be created or destroyed."

2) **The Law of Definite Proportions** – Joseph Proust
   "A given compound always contains exactly the same proportion of elements by mass."
   EX: oxygen makes up about $^{8}/_{9}$ of the mass of any sample of pure water, while hydrogen makes up the remaining $^{1}/_{9}$ of the mass

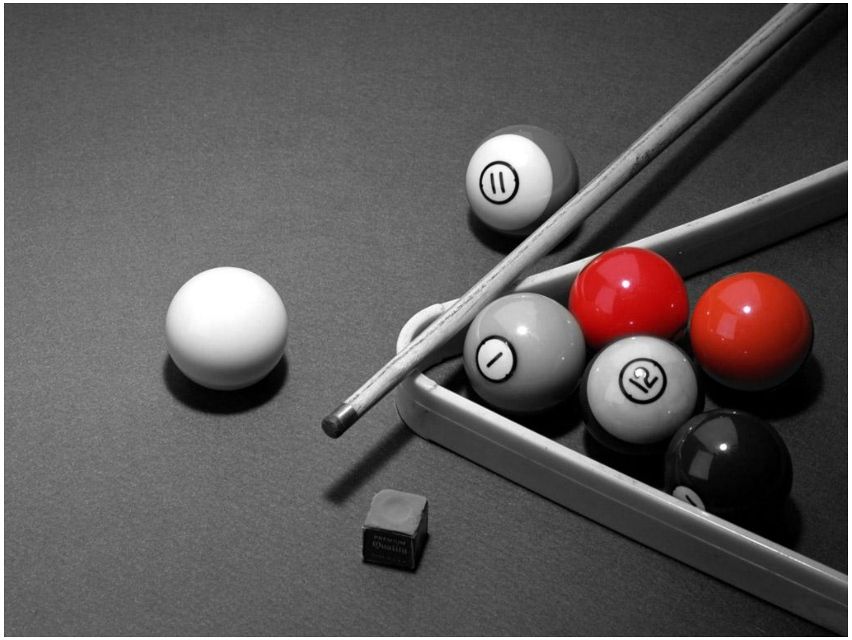
3) **The Law of Multiple Proportions** – John Dalton
   "When two elements form a series of compounds, the ratios of the masses of the second element that combine with 1 gram of the first element can always be reduced to small whole numbers."
   EX: A fixed mass of carbon, say 100 grams, may react with 133 grams of oxygen to produce one oxide, or with 266 grams of oxygen to produce the other. The ratio of the masses of oxygen that can react with 100 grams of carbon is 266:133 ≈ 2:1, a ratio of small whole numbers

Dalton’s Atomic Theory

- All matter is made up of indivisible particles called atoms
- Atoms of the same element are identical, and atoms of different elements are different
- Chemical compounds are formed when atoms combine with each other
- Chemical reactions involve reorganization of atoms, but the atoms themselves can not be created or destroyed

Dalton’s Model of the Atom

Billiard Ball



The atom is a featureless sphere

J.J. Thomson

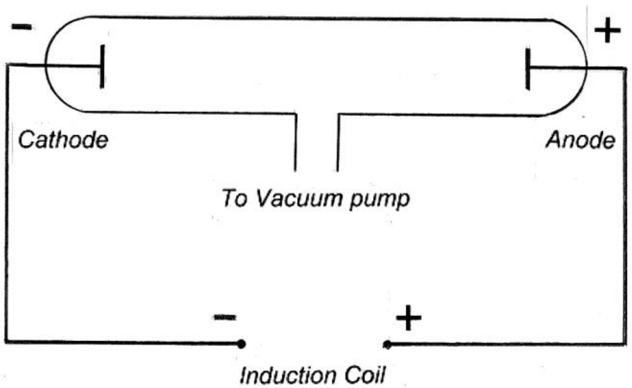
Thomson's atomic theory was also based on the experimental work of many other scientists who also used technology to make their observations

1) **Arrhenius** – studied the electrical nature of acids and bases and discovered that atoms form ions in solution

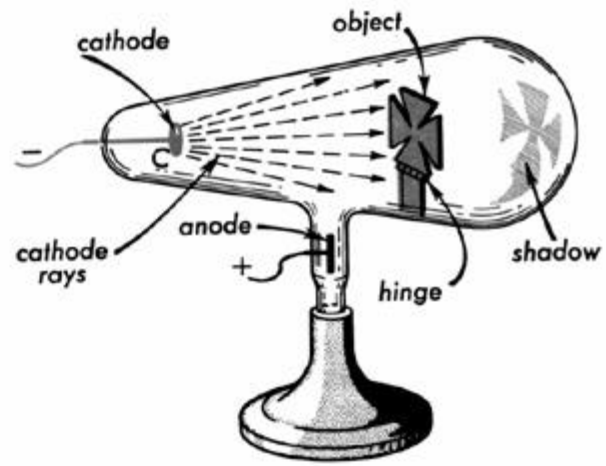
2) **Faraday** – worked with electricity and solutions and discovered that particular atoms and ions gain or lose a specific amount of charge

J.J. Thomson

3) **Crookes** – Used Cathode Ray Tubes (Electric Discharge Tubes) to demonstrate that electricity is composed of negatively charged particles

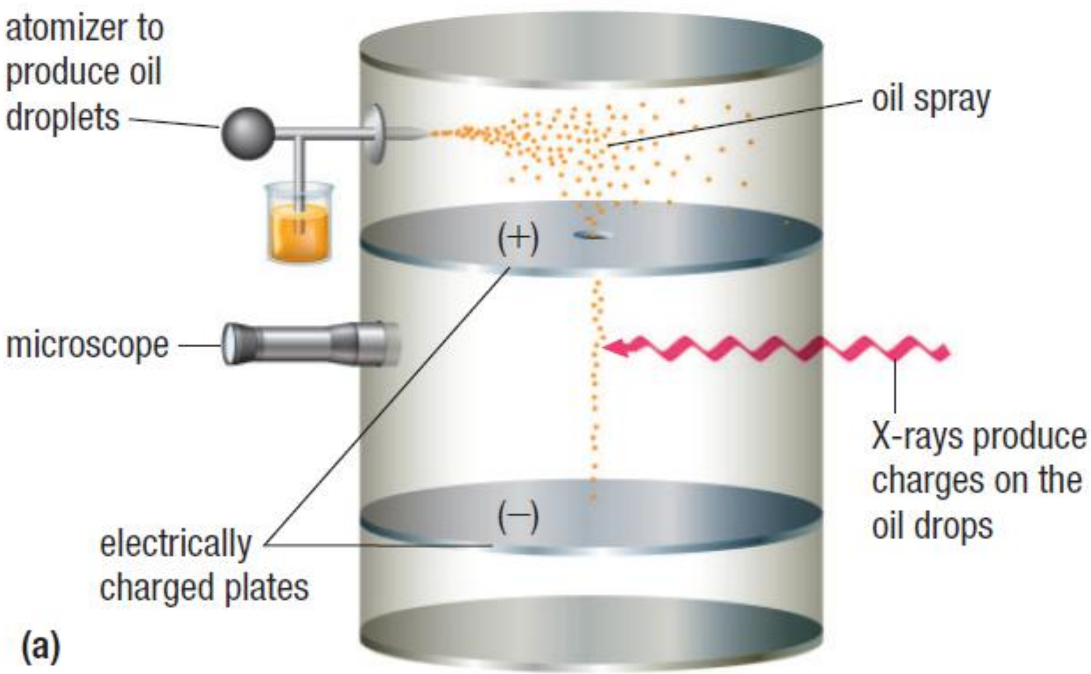


William Crookes
(1832-1919)



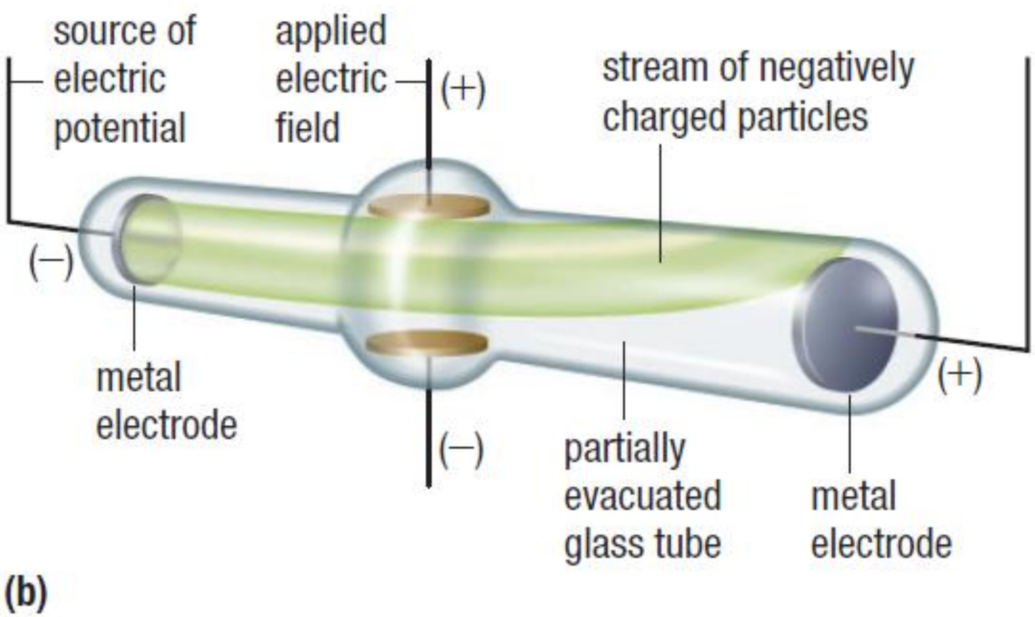
J.J. Thomspn

4) **Millikan** – Used his charged oil drop experiment to calculate the mass of an electron to be 9.11×10^{-31}kg



Thomson's Experiment

- He used the cathode ray tube



- Determined that the ray was composed of a stream of negatively charged particles which he called **electrons**

- Measured the deflection of the beam and was able to determine **the charge-to-mass ratio** of an electron

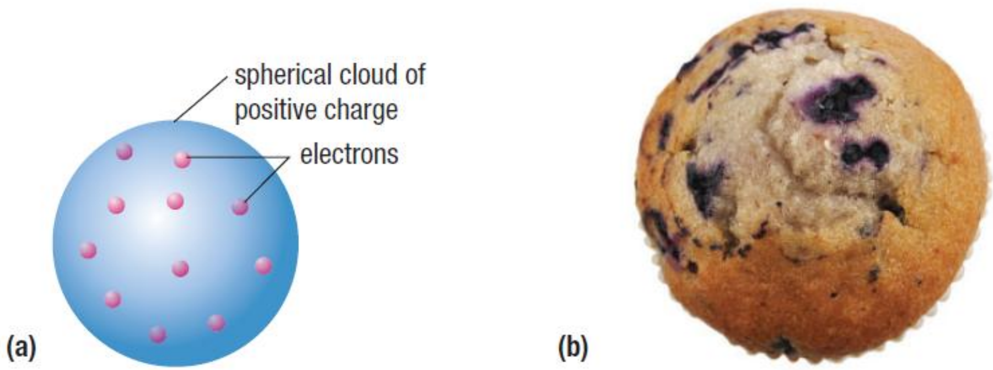
$$\frac{e}{m} = -1.76 \times 10^{8} C/g$$

- Reasoned that since atoms are electrically neutral, they must also contain a positive charge

Thomson’s Model of the Atom

Plum Pudding

(or Blueberry Muffin)

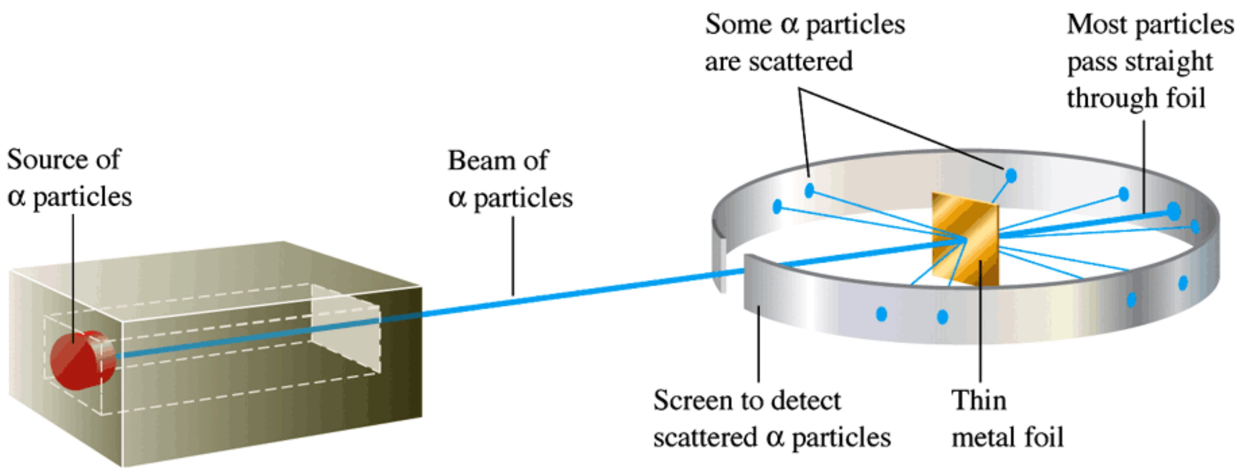


Ernest Rutherford

- Rutherford's atomic theory was also based on the experimental work of other scientists and was dependent on improved experimental technology
- Henri Becquerel was responsible for early research on radioactivity
- **Radioactivity** is the spontaneous decay or disintegration of the nucleus of an atom
- This led to Rutherford's discovery of the **alpha particle** (a small, dense, positively charged particle that is a type of radioactive emission)

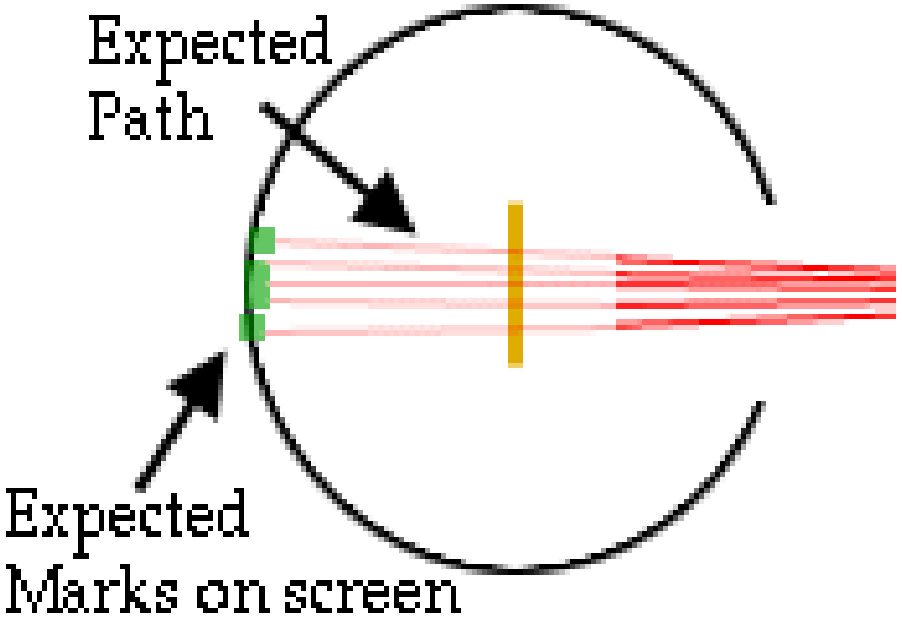
Rutherford's Famous Gold Foil Experiment

- Positively charged alpha particles were fired at a thin sheet of gold foil

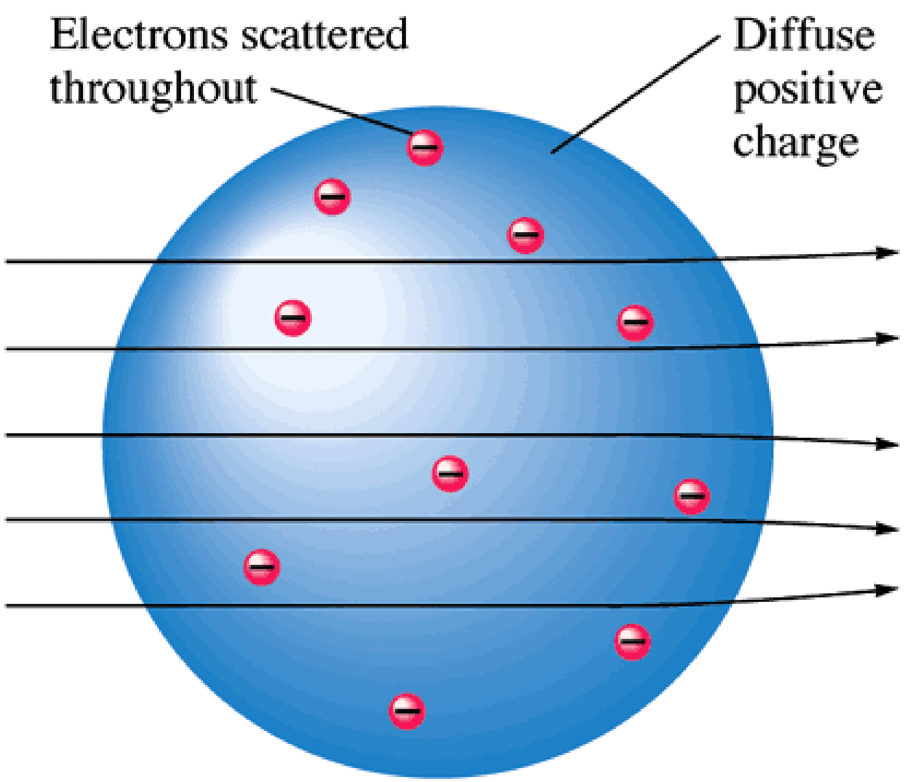


Rutherford’s Hypothesis

This is what he expected to see:

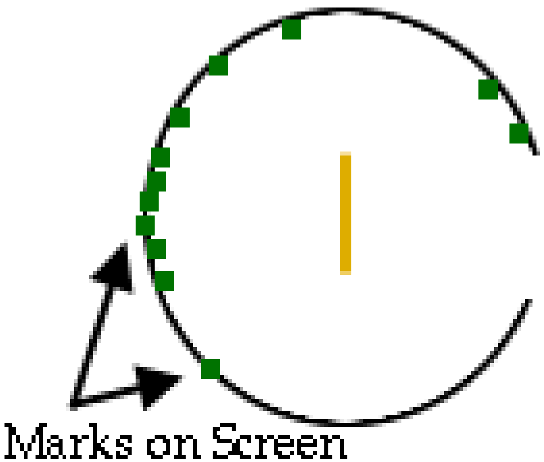


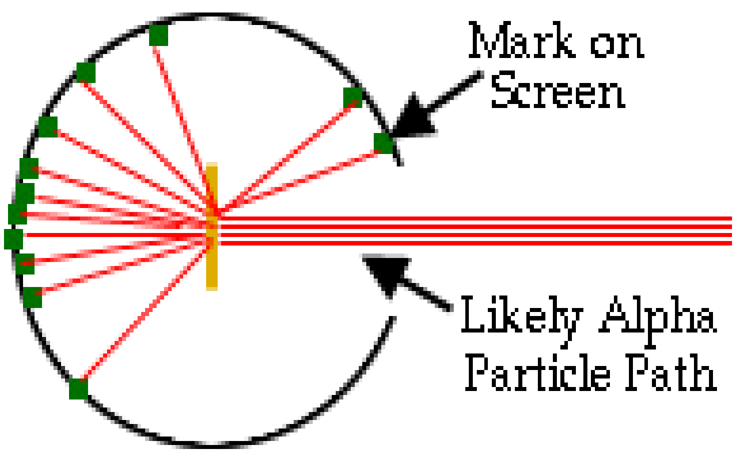
This is his reasoning:



Rutherford’s Results

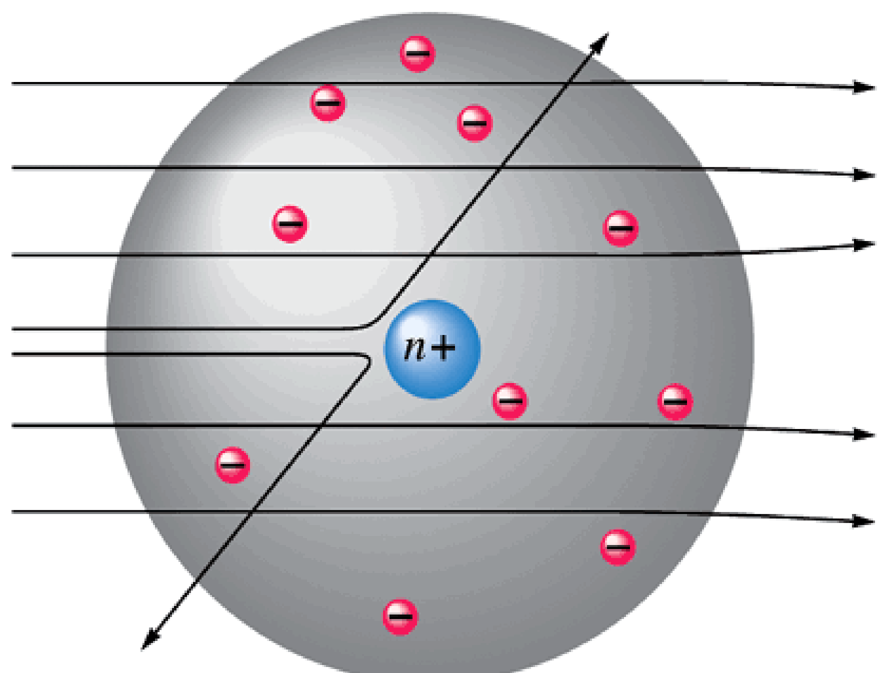
This is what he actually observed:





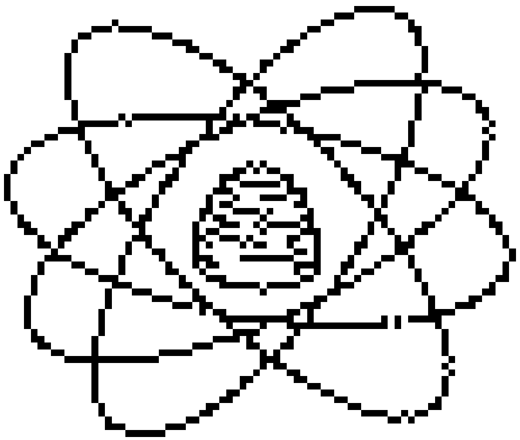
This is what he concluded:

- Most of the atom is empty space
- All of the positive charge of the atom (the protons) are concentrated in a dense central region (the nucleus)



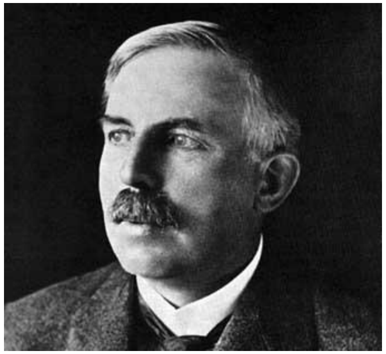
Rutherford’s Model of the Atom

Beehive



•A dense positive centre called the nucleus where most of the mass of the atom is located

•A cloud of negatively charged electrons swarming around the nucleus



Atoms and Isotopes

- Subatomic Particles Review:

Table 5.1 The Three Fundamental Subatomic Particles

NAME	SYMBOL	CHARGE	MASS (AMU)	MASS (G)	LOCATION
proton	p^+	1+	1.007	1.673×10^{-24}	nucleus
neutron	n^0	0	1.009	1.675×10^{-24}	nucleus
electron	e^-	1−	5.486×10^{-4}	9.109×10^{-28}	outside nucleus

Atoms and Isotopes

- The **Atomic Number (Z)** is the number of protons in the nucleus
- The number of protons is what makes atoms of each element unique
- Since atoms are electrically neutral, they have the same number of protons and electrons
- The number of electrons in an atom, and their arrangement determine the physical properties and chemical behaviour of the atom
- **Mass Number (A)** is the total number of protons and neutrons in the nucleus

ATOMIC SYMBOLS *e.g.*, "carbon twelve"

"*A*" Mass number
p^+ + # n^0

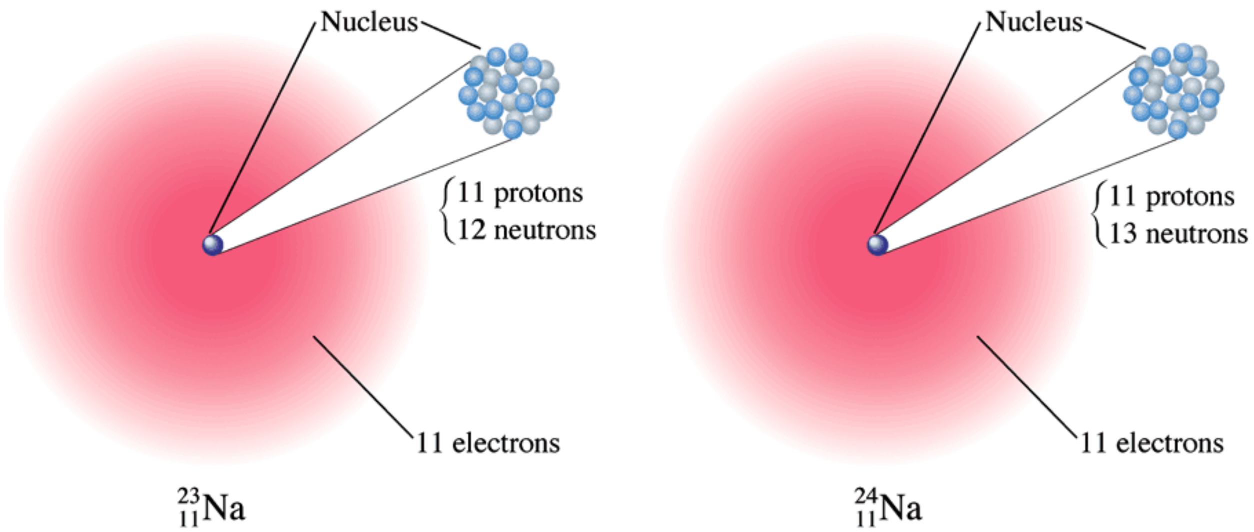
$^{12}_{6}\mathrm{C}$

Element symbol

"*Z*" Atomic number
p^+ (= # e^-)

Atoms and Isotopes

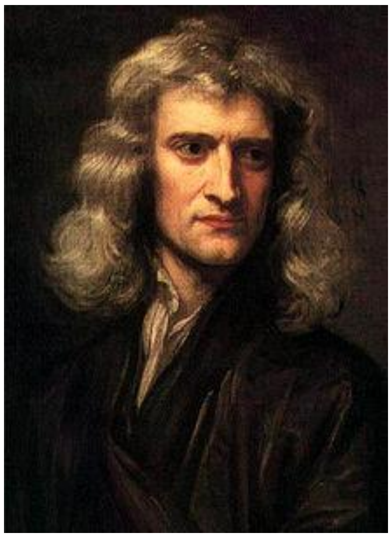
- Two atoms with the same number of protons but different number of neutrons are called **isotopes**



- A **radioisotope** is an isotope with an unstable nucleus that decays and emits gamma rays and/or subatiomic particles

The Debate on Light

Isaac Newton



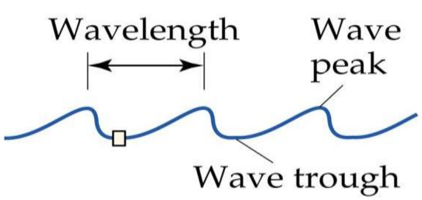
Light is a **PARTICLE**!

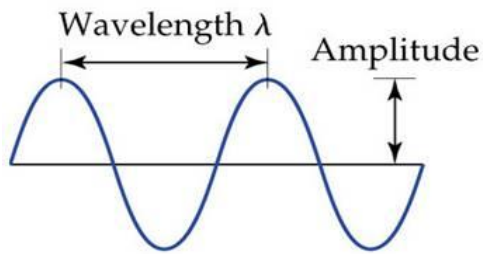
No! It's not!
Light is a **WAVE**!

Christiaan Huygens

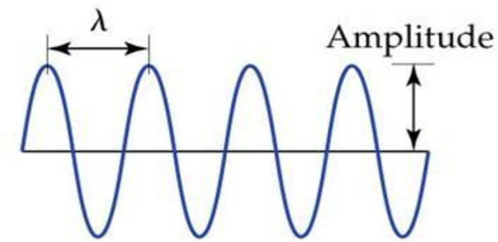
The Classical Theory of Light

- James Maxwell proposed that light could act on charged particles because it existed as an electromagnetic wave made of magnetic and electric fields

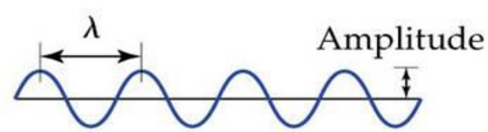




(a) Two complete cycles of wavelength λ



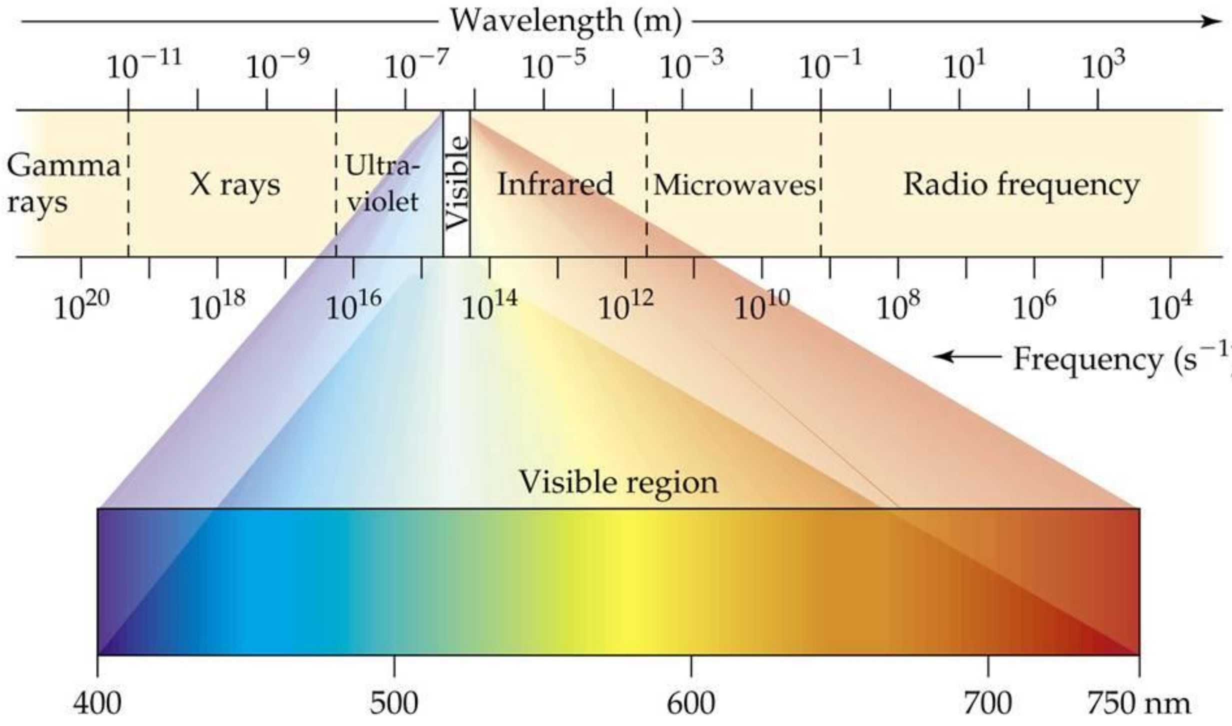
(b) Wavelength half of that in (a); frequency twice as great as in (a)



(c) Same frequency as (b), smaller amplitude

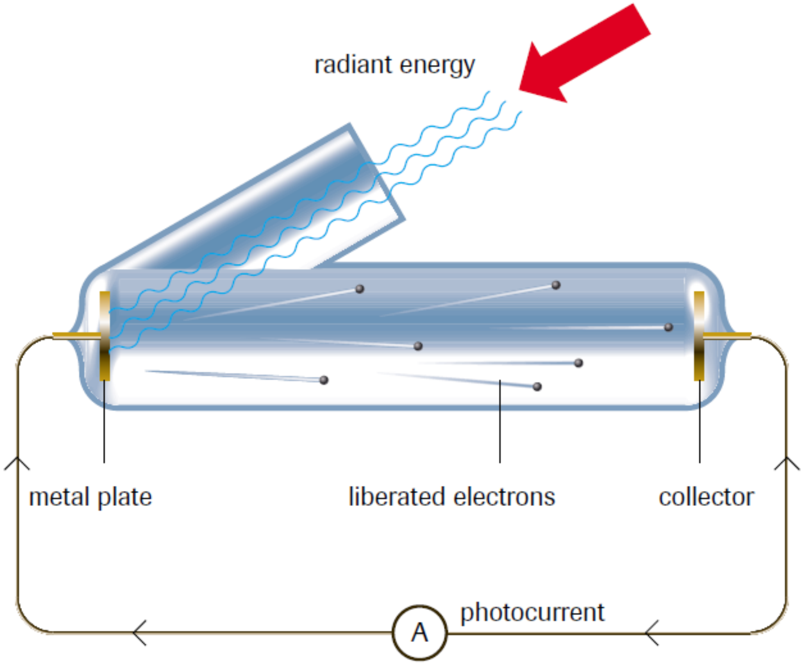
The Classical Theory of Light

- Light is an electromagnetic wave composed of continuous wavelengths that form a spectrum



The Photoelectric Effect

- Heinrich Hertz
- Electrons are emitted by matter that absorbs energy from shortwave electromagnetic radiation



The Photoelectric Effect

- Hertz's experiments demonstrated that the colour of the light was most important in determining the energy of the emitted electrons

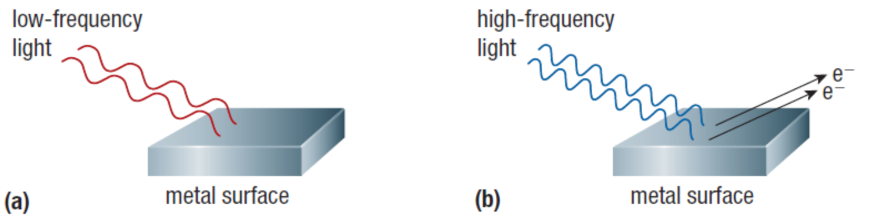
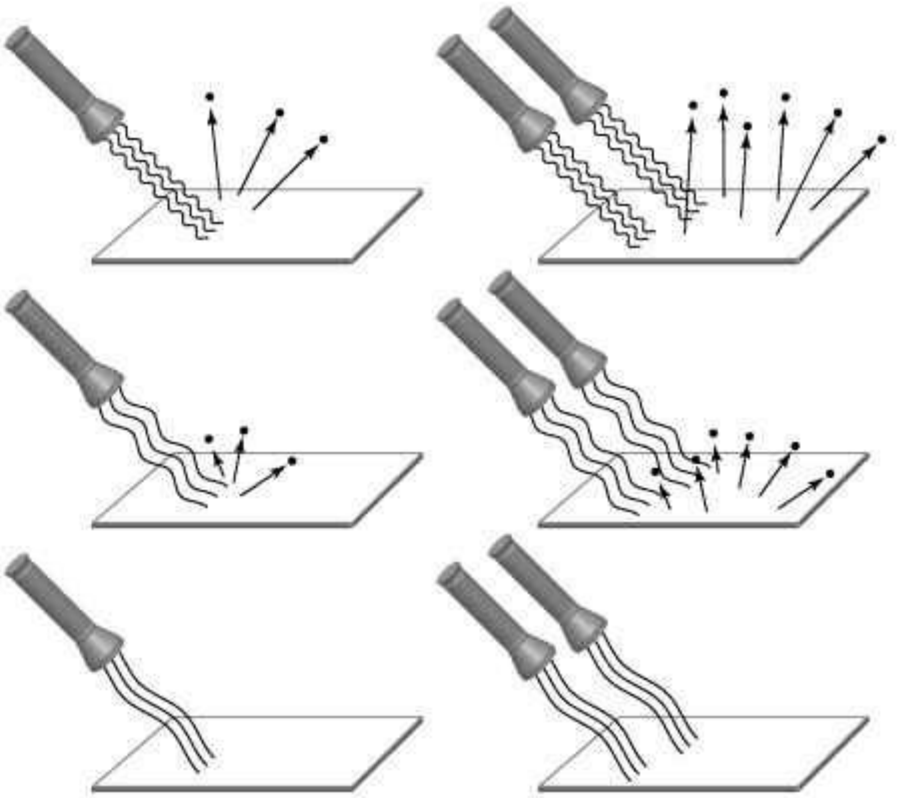


Figure 12 Hertz's experiments showed that light with frequency less than a certain frequency, called the threshold frequency, produces no electrons (a), whereas light with frequency higher than the threshold frequency causes electrons to be emitted from the metal (b).



- The classical theory of light could not explain these observations, so it began to be viewed as flawed

Planck's Quantum Hypothesis

- Max Planck conducted experiments where he heated solids to high temperatures causing them to glow different colours

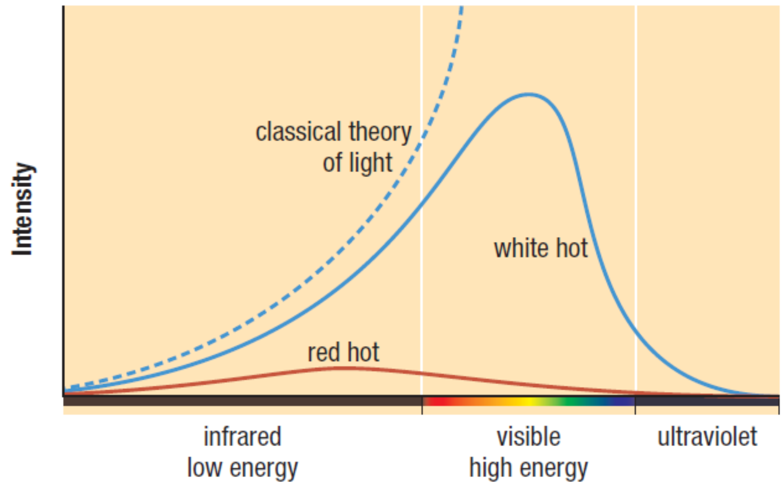


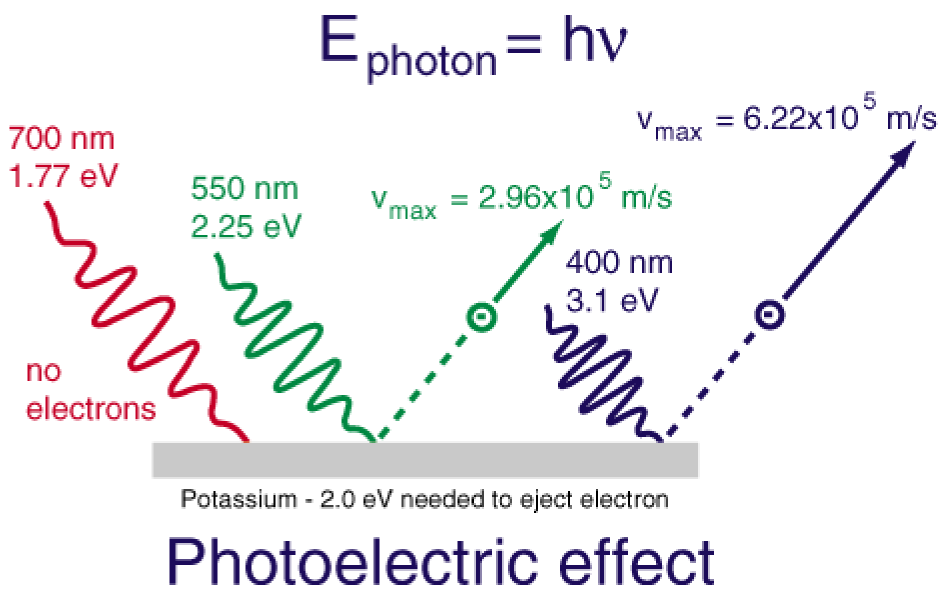
Figure 14 A white-hot wire and a red-hot wire emit light at different colours and intensities. The light emitted does not follow the expected results of the classical theory of light.

Planck's Quantum Hypothesis

- Planck postulated that matter can gain or lose energy, *E*, only in whole number multiples according to the equation

$$E=hf$$

- Where *f* is the frequency of radiation and *h* is Planck's constant (6.63x10^{-24}J·s)



One burst or packet of energy is known as a **quantum** of energy

A **photon** is a quantum of *light* energy

Einstein and Planck

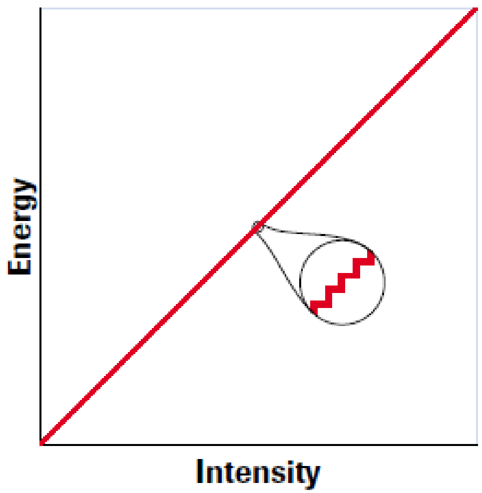


Figure 3
Scientists used to think that as the intensity or brightness of light changes, the total energy increases continuously, like going up the slope of a smooth hill. As a consequence of Planck's work, Einstein suggested that the slope is actually a staircase with tiny steps, where each step is a quantum of energy.

Einstein and Photons

- Einstein suggested that electromagnetic radiation could be viewed as a stream of particles called photons
- A **photon** is a quantum of light energy
- Einstein explained the photoelectric effect by proposing that an electron was emitted from the surface of the metal because a photon collided with the electron
- Some of the transferred energy caused the electron to break away from the atom, and the rest was converted to kinetic energy
- If a single electron absorbs a single photon with the right quantity of energy, the electron can escape the metal surface. If a photon does not have enough energy, no electrons can escape the metal no matter how many photons strike it

Einstein and Photons

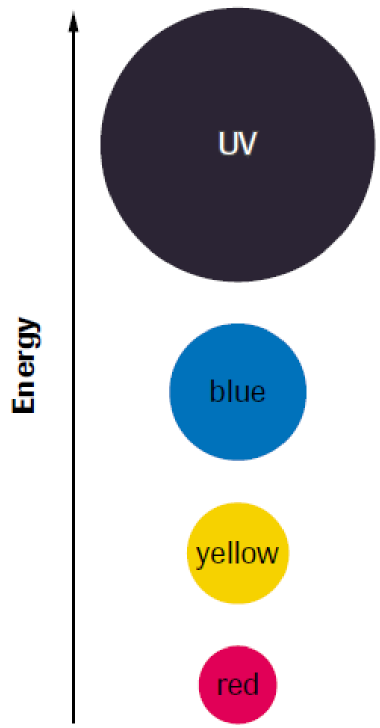


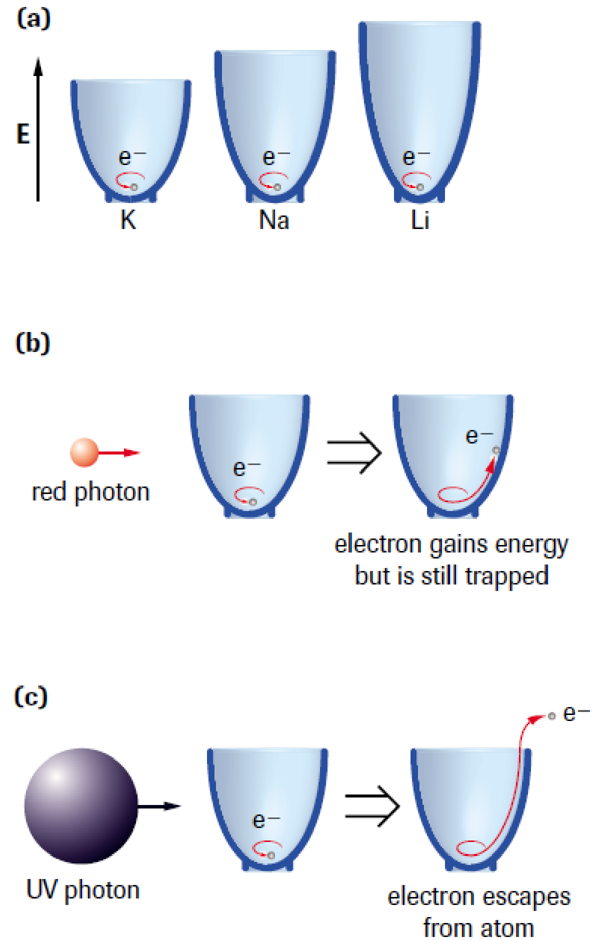
Figure 7
Each photon of light has a different energy, represented by the relative sizes of the circles.

Figure 8

(a) Using a bowl analogy, different atoms would be represented with bowls of different depths.

(b) For most atoms, the energy of a red photon is not great enough to boost the electron (marble) out of the atom (bowl). The electron can absorb the energy but is still stuck in the atom. This process simply results in the heating of the sample.

(c) A higher-energy photon, such as a UV photon, has more than enough energy to boost the electron out of many atoms.



HOMEWORK

Required Reading:

p. 132-142

(remember to supplement your notes!)

Questions:

p. 142 #1-8, 10

"Of course the elements are earth, water, fire and air. But what about chromium? Surely you can't ignore chromium."