McGraw-Hill Ryerson

BC Science Connections 8

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UNIT 2

The behaviour of matter can be explained by the kinetic molecular theory and atomic theory

TOPIC 2.4

How can we investigate an explain the composition of atoms?

Topic 2.4: How can we investigate an explain the composition of atoms?

- Late 1800s and early 1900s:
  - Scientists conducted experiments to study the structure of particles that make up matter
  - Developed the atomic theory

- Present day:
  - Atomic theory is still developing

A frame from the smallest movie in the world, “A Boy and His Atom”. Each dot is an oxygen atom.

Concept 1: Dalton developed an early atomic theory.

Greek philosophers and *Atomos*

- Democritus: proposed the idea that matter was made up of tiny particles that exist in empty space
  - Particles were called *atomos* ("uncuttable") because they could not be created, destroyed, or divided
- Aristotle: Did not believe that empty space could exist
  - More influential than Democritus
  - Denial of existence of atoms lasted for 2000 years

Figure 2.21: If Democritus and Aristotle used social media, their posts might have looked like this.

Democritus

share | reply   2,359   1

- Matter is composed of small particles in empty space.
- The particles are solid, indestructible, and indivisible.
- Different types of particles have different shapes and sizes.
- Characteristics of the particles determine the properties of matter.

Aristotle Come on. Empty space?! Impossible.

Aristotle

share | reply   1   1,343,987

- Empty space cannot exist.
- Matter is made of earth, air, fire, and water.

Plato You tell him.

share | reply

Atomic Theory Begins

- Idea of *atomos* was philosophical:
  - Democritus used reason and logic, but not experiments, to support the idea
- John Dalton (1800s):
  - Used controlled scientific experiments to support the idea of *atomos*

Figure 2.22: John Dalton, schoolteacher and scholar

Dalton's Theory of the Atom

- All matter is made of extremely small particles called atoms.
- Atoms cannot be created, destroyed, or divided.

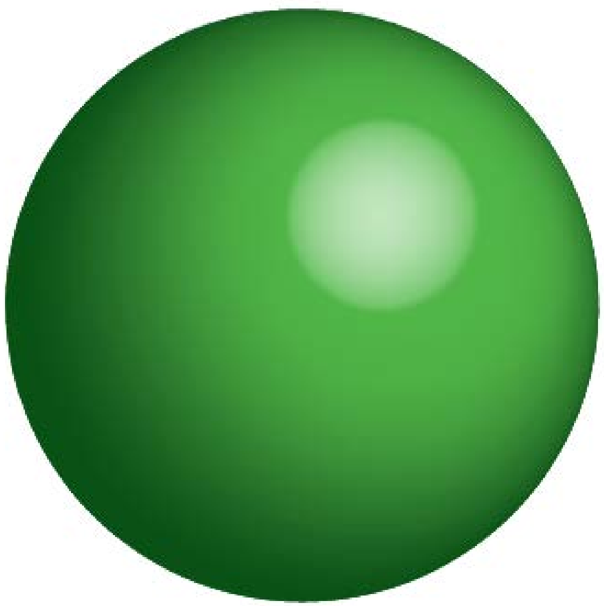


Figure 2.23: According to Dalton, atoms were solid, indestructible spheres.

Dalton's Theory of the Atom

- All atoms of the same element are identical in size, mass, and chemical properties.
  - Atoms of a specific element are different from those of another element.

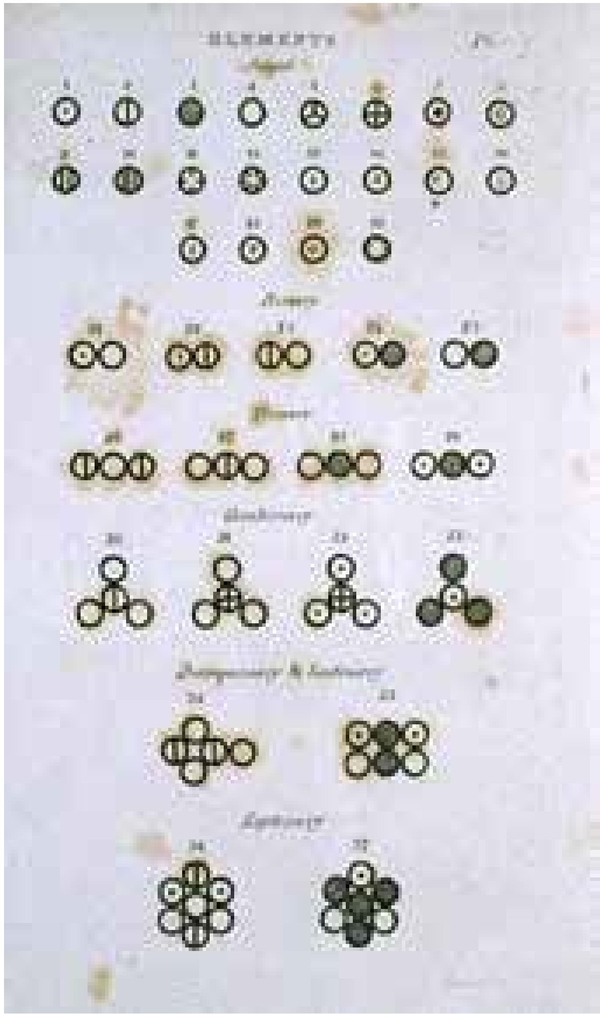
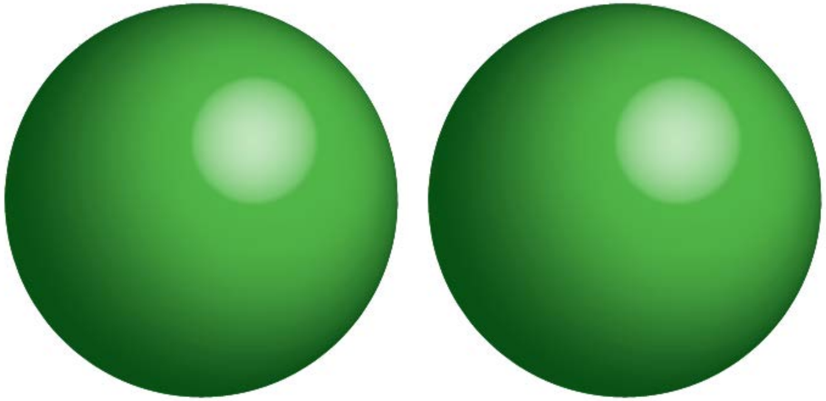


Figure 2.23: A page from Dalton's book which shows the symbols he used to represents atoms of different elements.

Dalton's Theory of the Atom

- Different atoms combine in simple whole-number ratios to form compounds.
  - In a chemical reaction, atoms are separated, combined or rearranged.



Discussion Questions

- Compare and contrast Democritus's *atomos* with Dalton's atomic theory
- How is a philosophical idea different from a scientific theory?

Concept 2: Many scientists contributed to the further development of atomic theory.

- Dalton's theory was adjusted and refined by other scientists, including:
  - JJ Thomson
  - Ernest Rutherford
  - Niels Bohr

JJ Thomson and the Electron

- 1897: JJ Thomson
  - Studied electric currents in cathode ray tube
  - When a battery is attached to the tube, a cathode ray travels through it (cathode: negative terminal)
  - Performed experiments that showed the existence of negatively charged particles

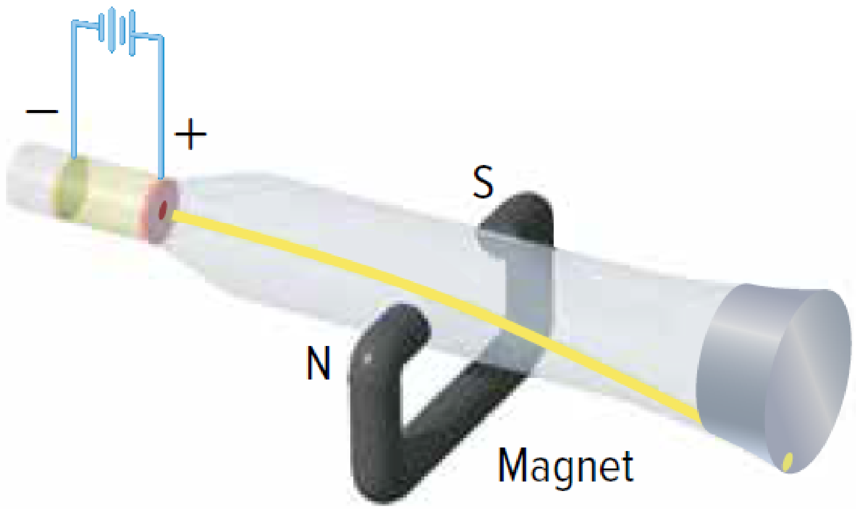
Figure 2.24: Fluorescent lights are examples of cathode ray tubes.

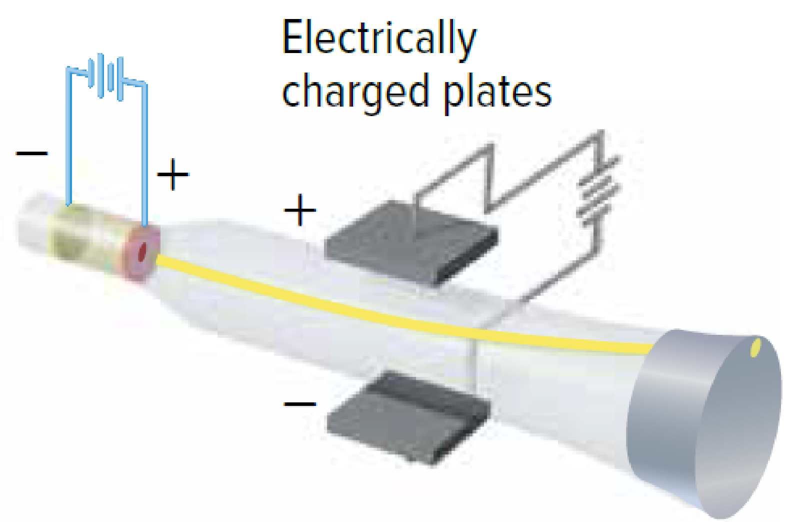
Thomson's Cathode Ray Tube Experiment

A

The cathode ray is deflected by the magnets. This means the particles in the ray must be charged.

The cathode ray is attracted to the positively charged plate. Opposites attract: the particles in the ray must be negatively charged.





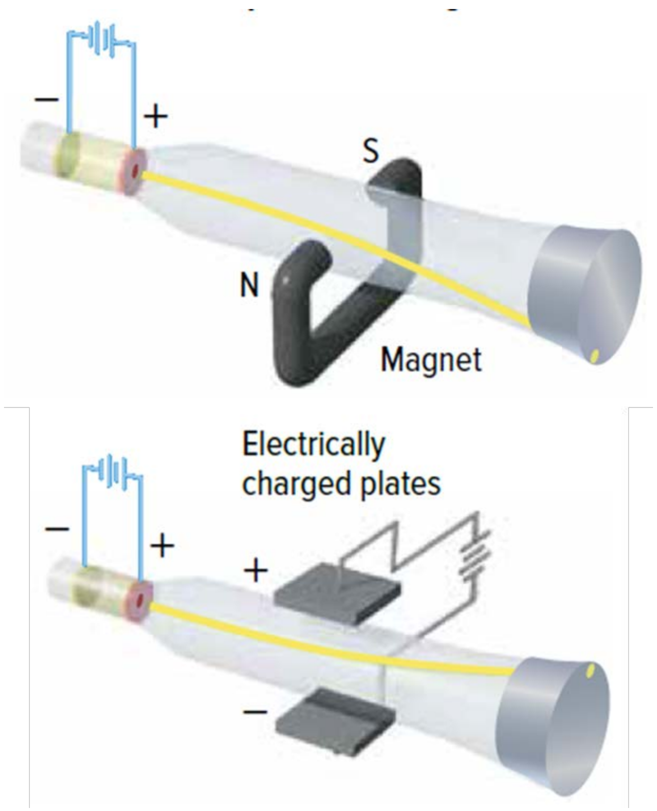
The amount of deflection of the rays gave Thomson information about the ratio of the charge of the particles to their mass.

Figure 2.24: Thomson used magnets and charged plates to manipulate cathode rays and measure the effects.

Thomson's Cathode Ray Tube Experiment

Conclusions from Thomson's experiments:

- Cathode rays: streams of negatively charged particles
- Mass of charged particles were much less than an atom of hydrogen
  - There are particles smaller than the atom; contradicts Dalton's theory that atoms are indivisible
- All substances produced these particles, called **electrons**



Thomson's Model of the Atom

- "Plum-pudding" or blueberry muffin model of the atom:
  - Positively charged ball (the "muffin") with negatively charged electrons embedded (the "blueberries")

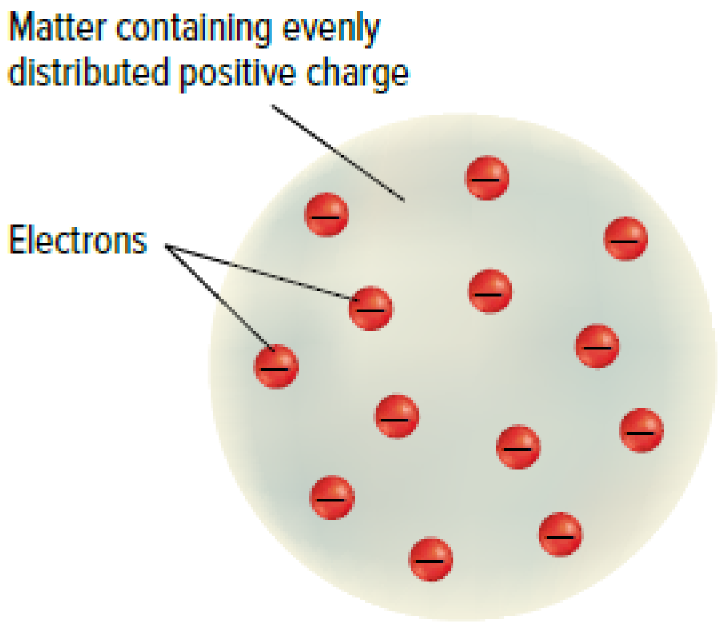


Figure 2.25: Thomson's model of the atom.

Thomson's Contribution to Modern Atomic Theory

- Atoms are not indivisible.
- Atoms contain smaller, negatively charged particles known as electrons.

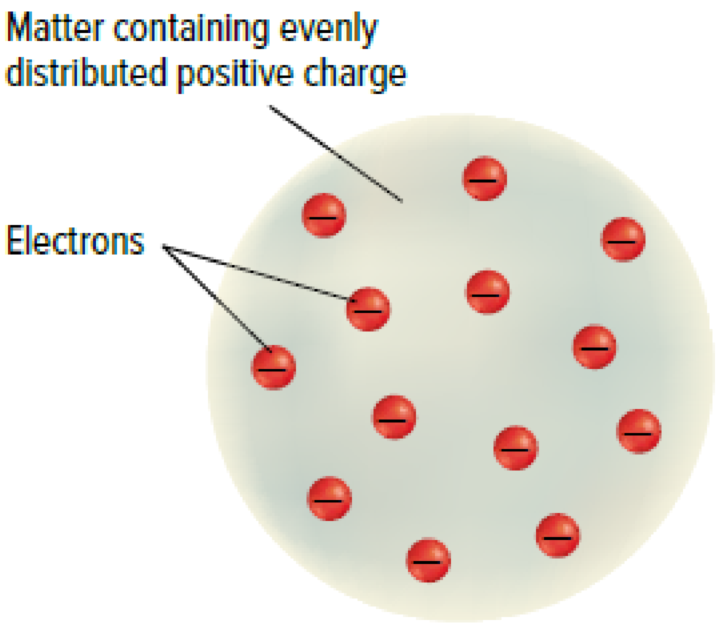


Figure 2.25: Thomson's model of the atom.

Ernest Rutherford and the Nucleus

- 1909: Ernest Rutherford
  - Scientist who designed an experiment to find out more about the structure of the atom
  - Rutherford's gold foil experiment led to the discovery of the atom's nucleus

Rutherford's Gold Foil Experiment

Gold foil experiment:

- Exposed a sheet of gold to positively-charged alpha particles (like tiny bullets)
- Wanted to see how the alpha particles interacted with the gold atoms in the foil
- Most alpha particles went through the gold atoms
- Some alpha particles rebounded from the gold foil

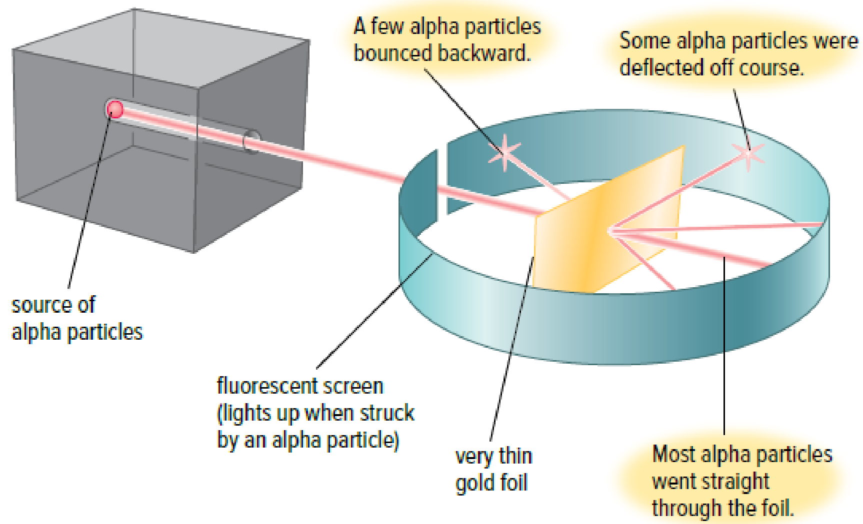


Figure 2.26: Rutherford's gold foil experiment.

Rutherford's Gold Foil Experiment

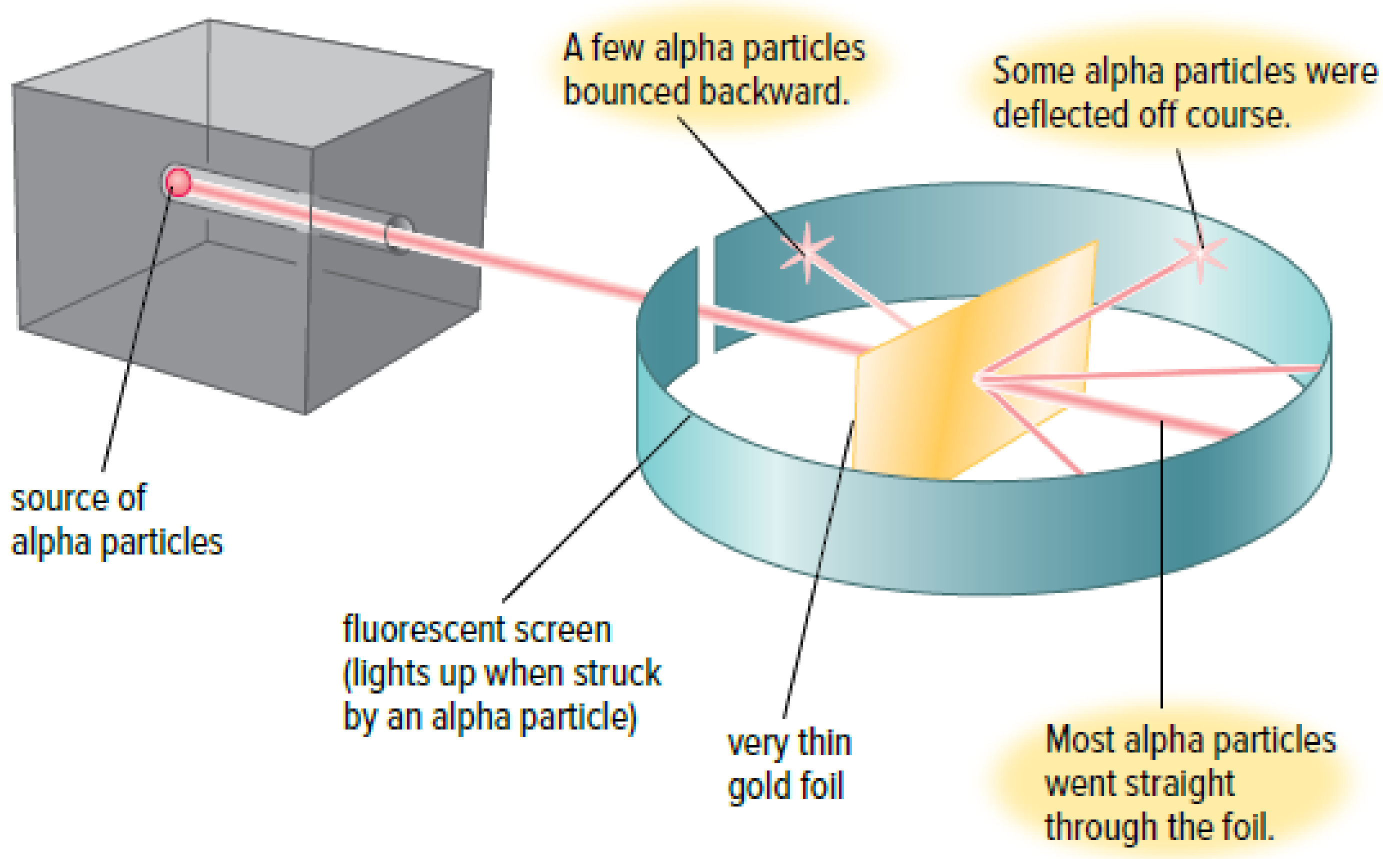


Figure 2.26: In Rutherford's experiment, most of the alpha particles went straight through the foil. But a few bounced back.

Rutherford's Gold Foil Experiment

Conclusions from Rutherford's gold foil experiment:

- Some of the alpha particles bounced back from the foil
  - These alpha particles must have hit a tiny, dense structure in the gold atoms
  - This structure is the **nucleus**: positively charged center of the atom

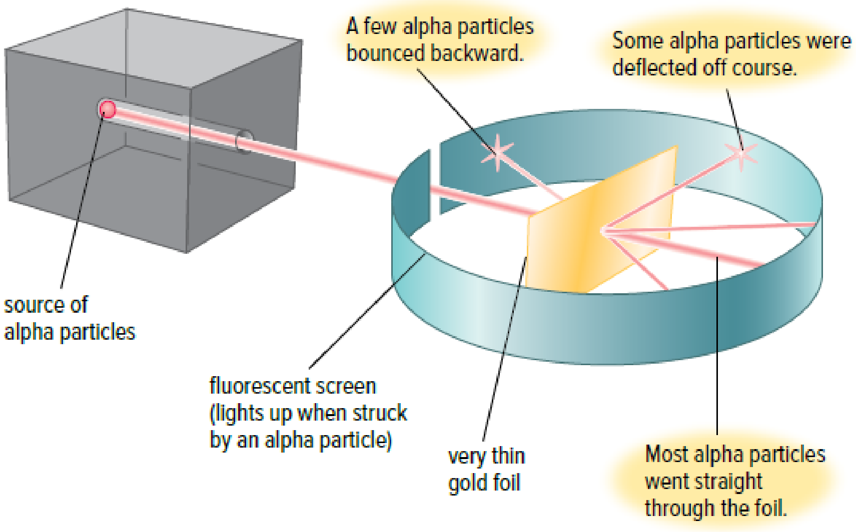


Figure 2.26: Rutherford's gold foil experiment.

Rutherford's Model of the Atom

- Revised model of the atom:
  - Dense nucleus with a positive charge that is very tiny compared to the atom
  - Electrons move freely in the space surrounding the nucleus

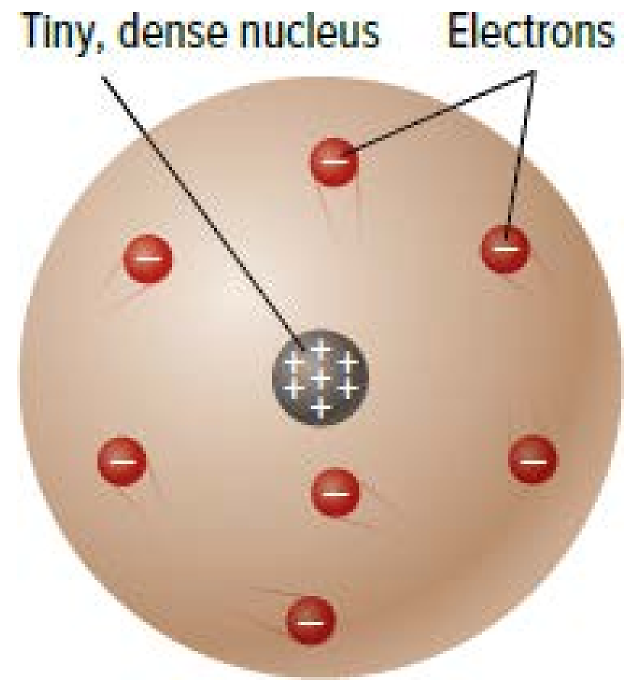


Figure 2.27: Rutherford's revised model of the atom.

Nucleus: Contains Protons and Neutrons

- 1920: Rutherford and James Chadwick
  - Discovered that the nucleus contains positively charged particles (**protons**) and neutral particles (**neutrons**)

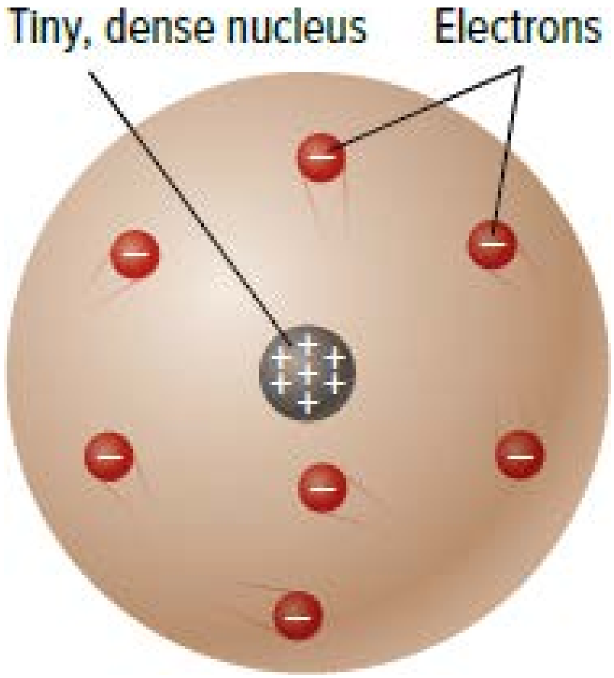


Figure 2.27: Rutherford's revised model of the atom.

Rutherford and Chadwick's Contribution to Modern Atomic Theory

- Most of the atom's volume is empty space with tiny, moving electrons (negatively charged)
- Positive charge in an atom is in a tiny, dense nucleus
  - Nucleus contains protons (positively charged) and neutrons (no charge)

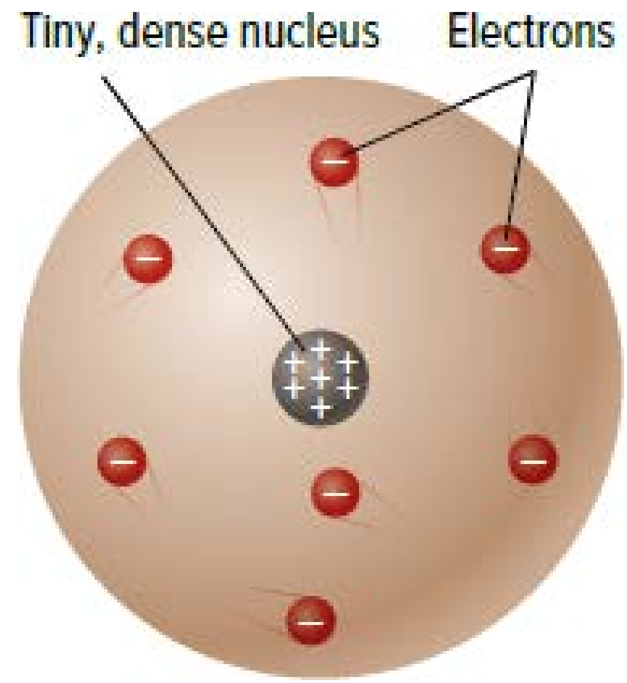


Figure 2.27: Rutherford's revised model of the atom.

Niels Bohr and Energy Levels

- 1913: Niels Bohr
  - Studied electrons
  - Performed experiments on light released by different gases
  - Each gas produced a spectrum of light (line spectrum)
  - The color of light emitted by gases is due to high-energy electrons releasing energy

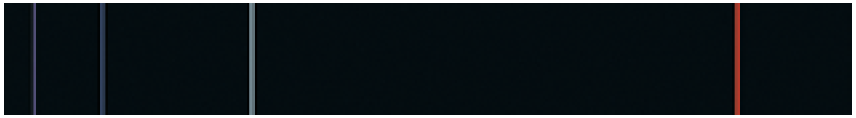


Figure 2.28: The line spectrum for hydrogen provides evidence that electrons can have only certain allowed energies.

Electron Energy Levels

- Conclusions from Bohr's experiments:
  - Electrons surrounding the nucleus can only occupy specific "energy levels" or "energy shells"
  - The larger the shell, the higher the energy of an electron occupying it

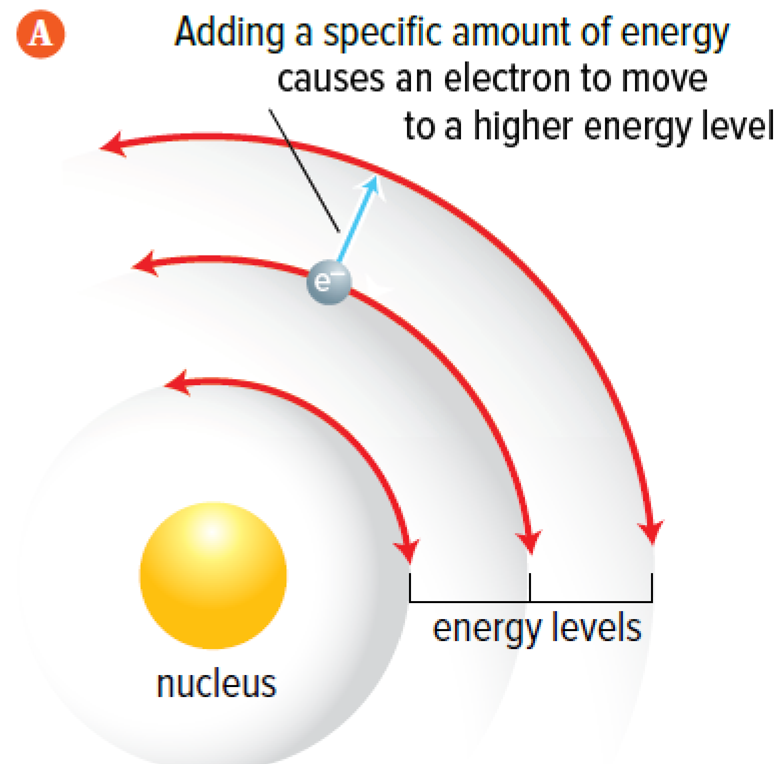


Figure 2.29: (A) Bohr's model of the atom

Electron Energy Levels

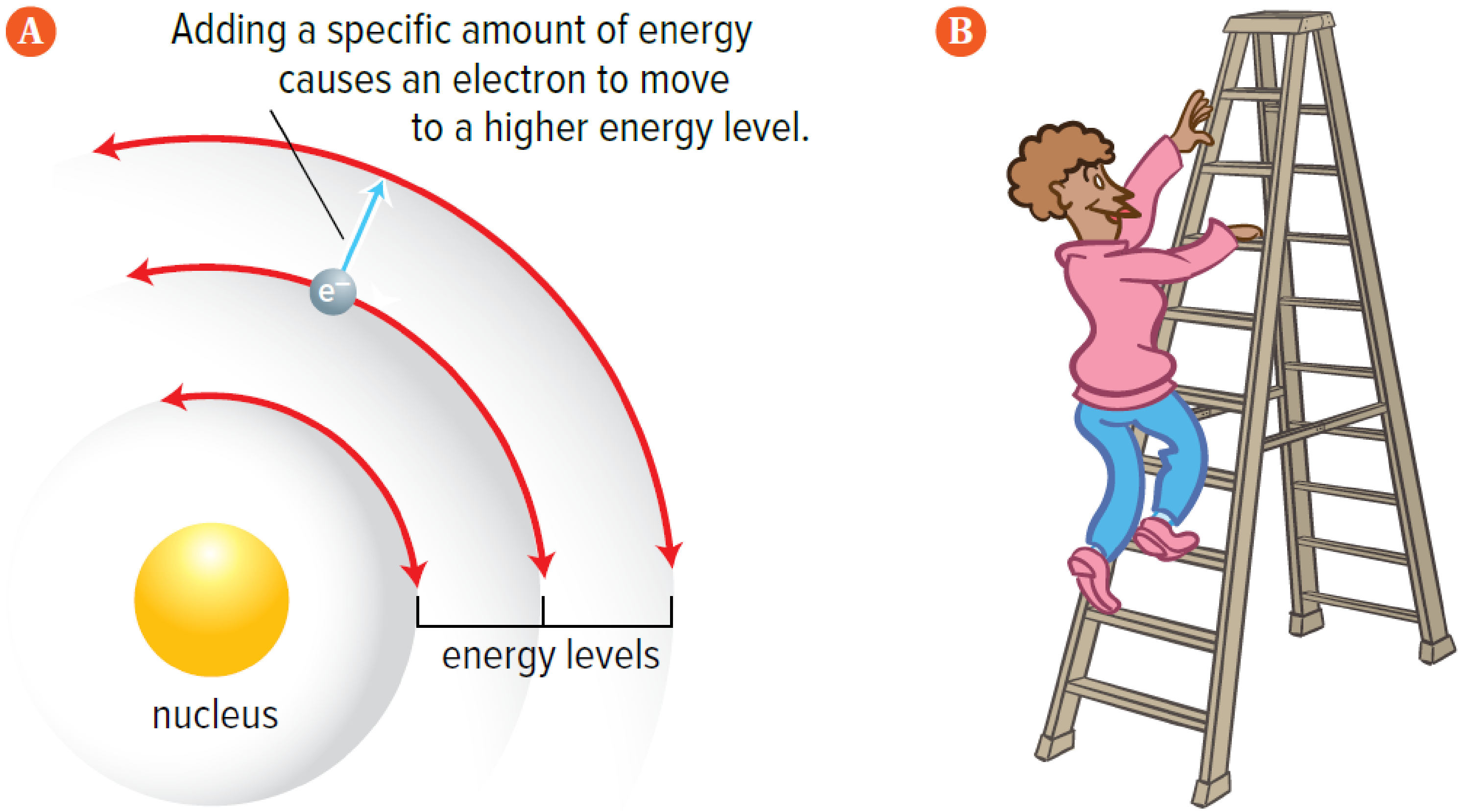


Figure 2.29: (A) Bohr’s model of the atom. (B) The energy shells are like rungs on ladder. When you climb a ladder, your foot can rest on any of the rungs but not in between.

Visible Effects of Electron Energy Shells

- Example: Neon light
  - When electricity is added to neon gas, electrons of neon atoms gain energy and jump to higher energy levels
  - Electrons can now fall back down to lower energy levels, releasing energy as light of a specific colour

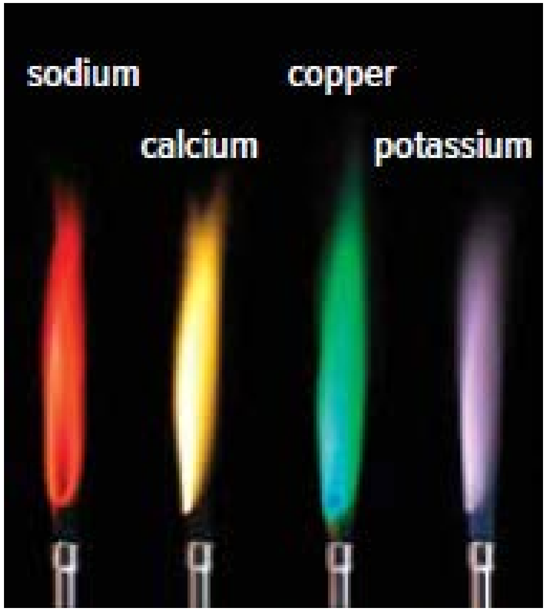
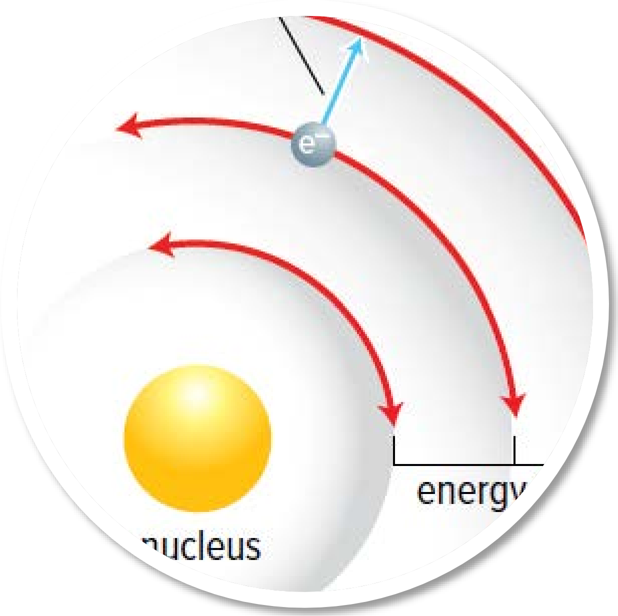


Figure 2.30: Flame tests work by placing a sample of a compound containing a metal element in a flame.

Discussion Questions

- Compare and contrast models of the atom.
- In your own words, describe Bohr's contribution to atomic theory.



Concept 3: An atom is made up of electrons, neutrons, and protons.

- **Atom**: the smallest particle of an element that retains the properties of that element
  - All matter is made up of atoms
  - Atoms are made up of subatomic particles

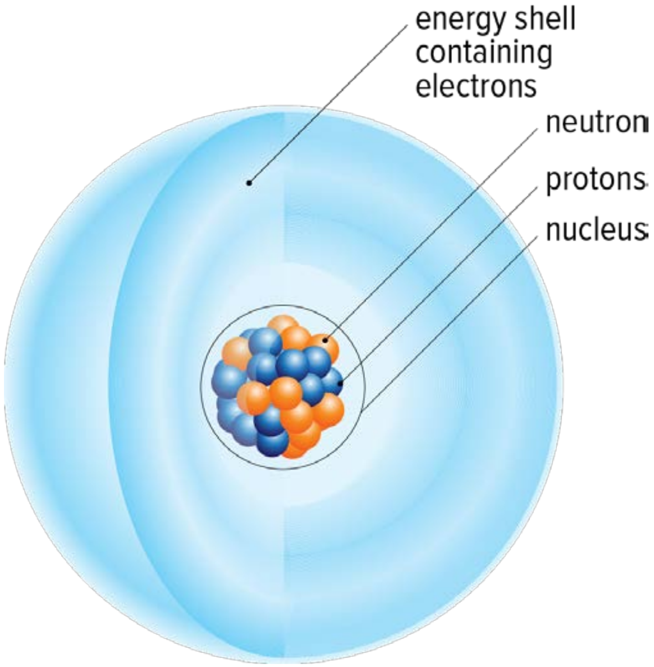


Figure 2.31: Model of the atom.

The Atom: Nucleus

Nucleus

- Tiny region at the centre of the atom
- Most hydrogen atoms: contain one proton
- All other atoms: contain both protons and neutrons
- Number of protons determines charge of the nucleus and the identity of an atom

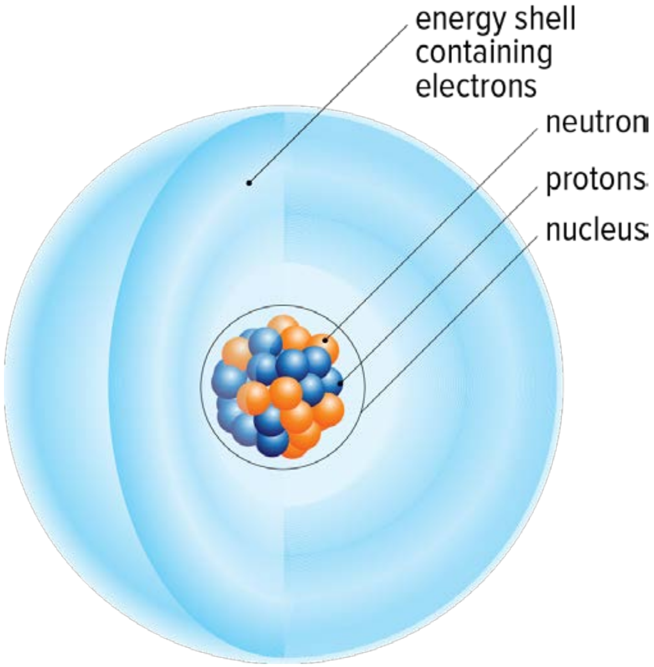


Figure 2.31: Model of the atom.

The Atom: Electron Energy Shell

Electron energy shell

- Region that electrons occupy accounts for over 99.99% of an atom's volume
- Electrons occupy specific regions (energy levels) that surround the nucleus
- Electrons are like a spread-out cloud of negative charge that exists in the whole region at once

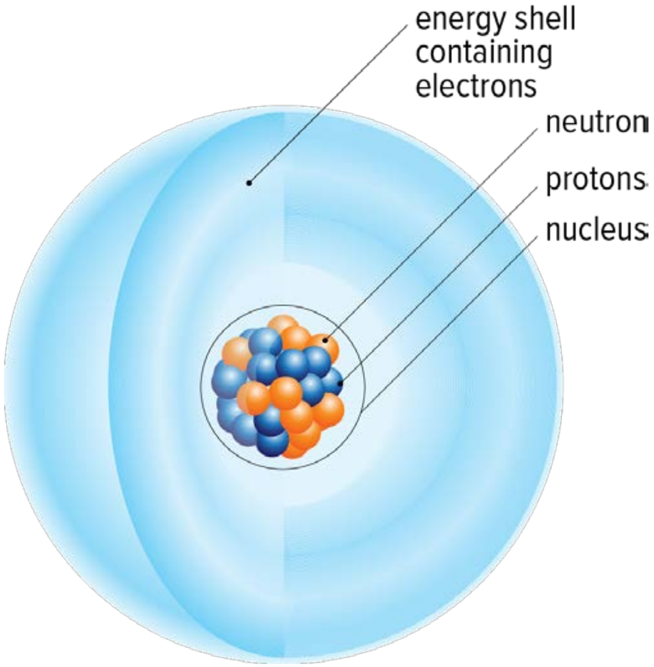


Figure 2.31: Model of the atom.

The Atom: Electric Charge

Electric Charge

- Comes in two types: positive and negative
- Protons: positive charge (1+ each)
- Electrons: negative charge (1– each)
- Neutrons: no charge
- Positive charge of protons in the nucleus attractions electrons
- Overall charge of an atom: uncharged/neutral (equal numbers of protons and electrons)

The Atom: Size

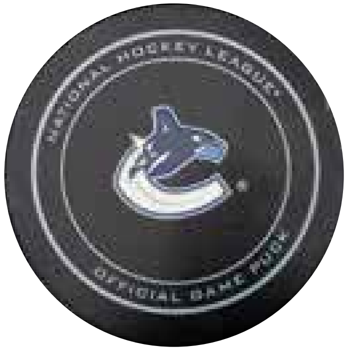
The Size of an Atom

- Atoms are incredibly small
- Suppose you enlarged everything on Earth so that an atom would become as big as a large apple
  - An apple would be as big as Earth

The Atom: The Size of the Nucleus Compared with an Atom

Size of the nucleus

- If a nucleus were the size of a hockey puck sitting at centre ice, the whole atom would include:
  - Entire rink
  - Seats
  - Building
  - Surrounding streets
  - Walkways/parking lot



The Atom: The Nuclear Force

Nuclear Force (Strong Force)

- Acts within nucleus to hold protons and neutrons together
- Very strong across very short distances
- Strong enough to counteract the repulsion between protons, keeping nucleus from flying apart

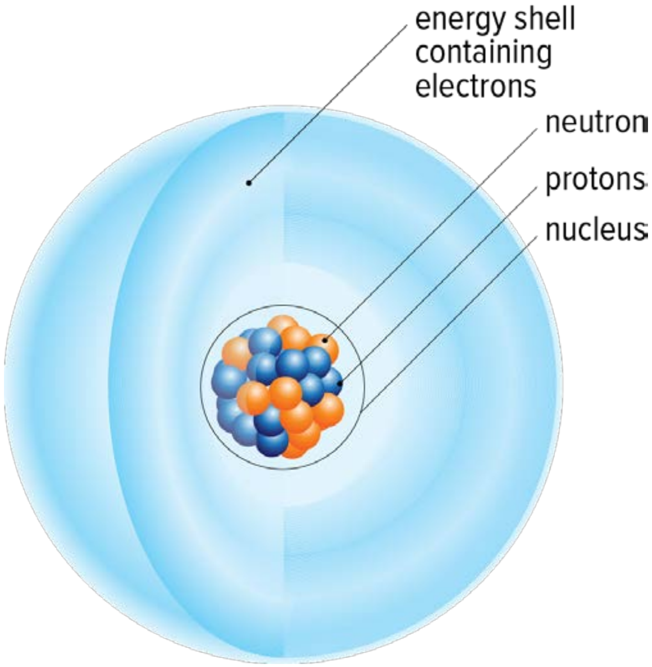


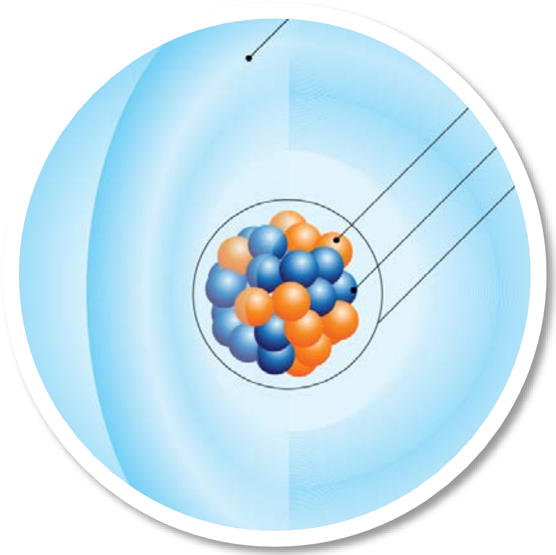
Figure 2.31: Model of the atom.

The Atom: Subatomic Particles

Name	Symbol	Electric Charge	Relative Mass	Location in the Atom
proton	p^+	1+	1836	nucleus
neutron	n^0	0	1837	nucleus
electron	e^-	1–	1	surrounding the nucleus

Discussion Questions

- What are the three subatomic particles?
- Compare and contrast the electron and the proton.



Discussion Questions

- Use an analogy to describe the size or composition of the atom.

- What does the existence of a nuclear force explain?

Concept 4: Atomic theory continues to develop.

- The atom is made up of smaller particles called subatomic particles
  - Some subatomic particles are made up of even smaller particles

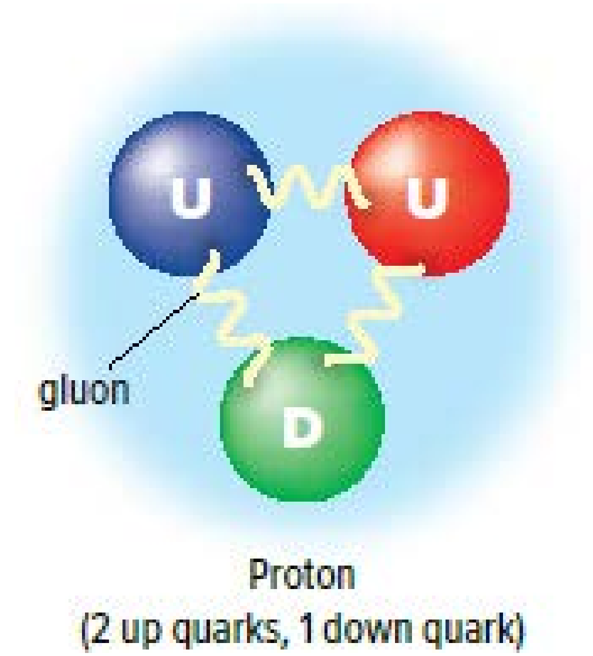


Figure 2.32: Protons are made up of smaller elementary particles

Quarks

- Quarks are elementary particles (cannot be split apart into smaller particles)
  - Six different "flavours" based on properties such as mass and charge: *up*, *down*, *strange*, *charm*, *top*, and *bottom*

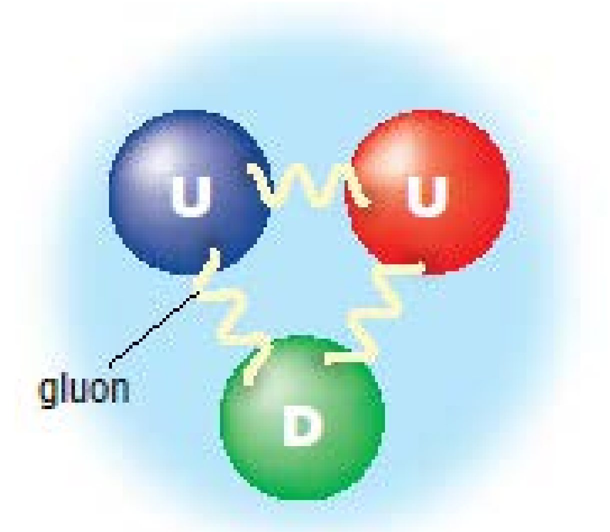


Figure 2.32: Protons are made up of smaller elementary particles

Quarks

- Protons and neutrons are composite particles (made up of quarks)
  - Also contain elementary particles called gluons, which act as a glue that binds quarks together
  - Experience the nuclear force (strong force), which is also involved in binding quarks together

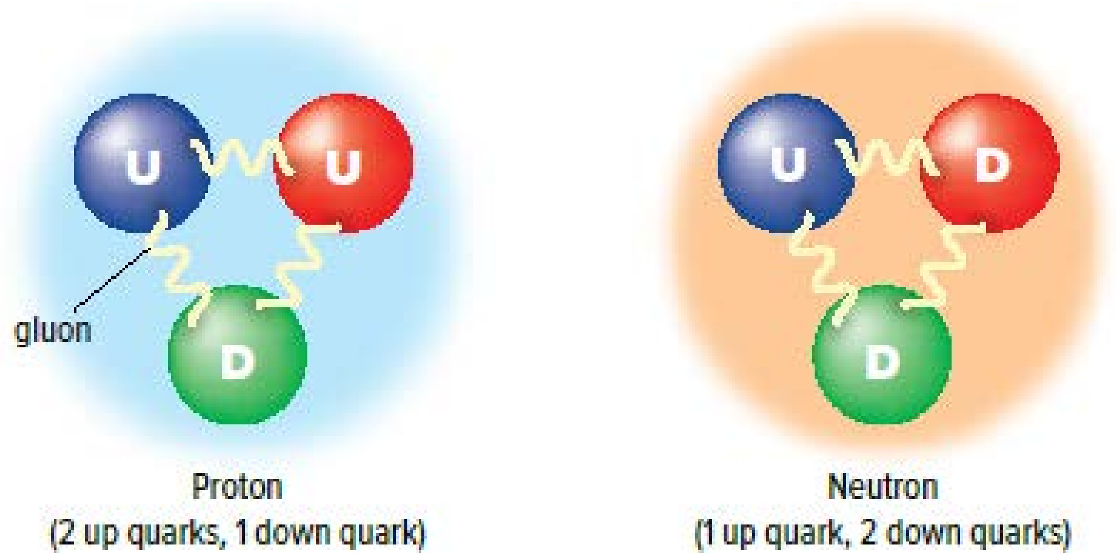


Figure 2.32: Protons and neutrons are made up of smaller elementary particles

Leptons

- Electrons are elementary particles called leptons
  - Come in six “flavours”: *electron*, *muon*, *tau*, *electron neutrino*, *muon neutrino*, and *tau neutrino*
  - Do not experience the nuclear force (strong force)

Table 2.4: Characteristics of Leptons

<table>
<tr><th>Lepton</th><th>Description</th></tr>
<tr><td>electron</td><td rowspan="3">• The electron is the lepton found in atoms.
• Compared to the electron, muon and tau particles have the same charge (1–) but a much greater mass.</td></tr>
<tr><td>muon</td></tr>
<tr><td>tau</td></tr>
<tr><td>electron neutrinos</td><td rowspan="3">• Neutrinos are very difficult to detect. They have no charge and are nearly massless.
• Trillions of them pass through our bodies each second.
• Neutrinos are produced by high-energy processes such as nuclear reactions in the Sun.</td></tr>
<tr><td>muon neutrinos</td></tr>
<tr><td>tau neutrinos</td></tr>
</table>

Research Continues: TRIUMF Cyclotron

TRIUMF cyclotron in Vancouver

- Built to research particles that make up matter
- Particle accelerator that produces a high-speed beam of protons
- The proton beam collides with various materials
- Detectors provide data about the products of the collisions

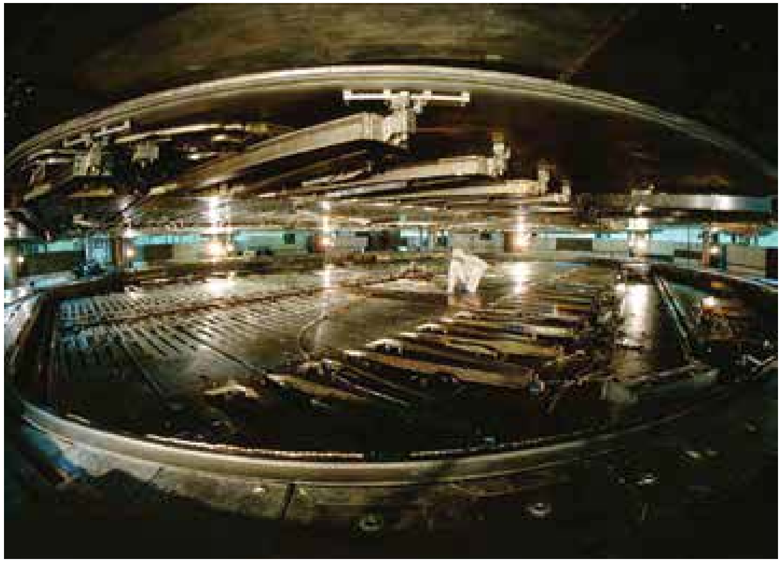
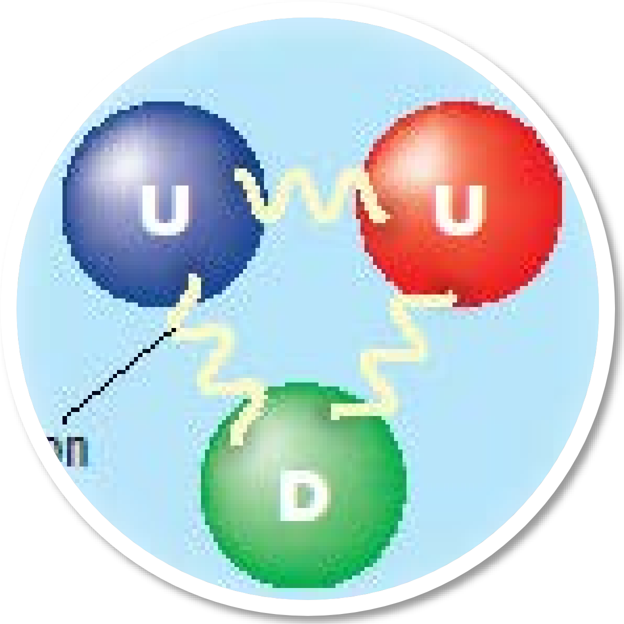


Figure 2.33: The TRIUMF cyclotron.

Discussion Questions

- Describe the structure of a proton.
- Compare neutrinos and electrons.



Summary: How can we investigate and explain the composition of atoms?

- Dalton developed an early atomic theory.
- Many scientists contributed to the further development of atomic theory.
- An atom is made up of electrons, neutrons, and protons.
- Atomic theory continues to develop.