How can we investigate and explain the composition of atoms?

SCIENCE 8

TOPIC 2.4

Summary

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.

Warm-up Questions

1. What is a “scientific theory”?
2. What are some misconceptions about scientific theories? Where do you think these misconceptions come from?
3. How are scientific theories developed?
4. What do you know about atoms? Where have you seen the word “atomic” before?

Internet Debates

Activity: Simulate a 'dumb' internet debate about one of the following, with a partner.

- Ice cream (bite or lick?)
- Pineapples on pizza
- Toilet paper roll direction
- Is water wet?

Based on this activity, and discussions/arguments you see on social media:

What tends to happen in these discussions? Who 'wins'? Is the winner always right?

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

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

Greek Philosophers and *Atomos*

Democritus (~460-370 BC):

- Matter is made up of **tiny particles** that **exist in empty space**
- Particles called ***atomos*** ("uncuttable") because they **could not be created, destroyed, or divided**

Aristotle (384-322 BC):

- Disagreed with Democritus: "Empty space cannot exist."
- More influential than Democritus; denial of existence of atoms lasted for 2000 years

Atomic Theory Begins

Idea of *atomos* was philosophical:

- Democritus used reason and logic, but not experiments, to support the idea

John Dalton (1766-1844):

- Used controlled scientific experiments to support the idea of *atomos*

Figure 2.22: John Dalton, schoolteacher and scholar

Dalton's Theory of the Atom

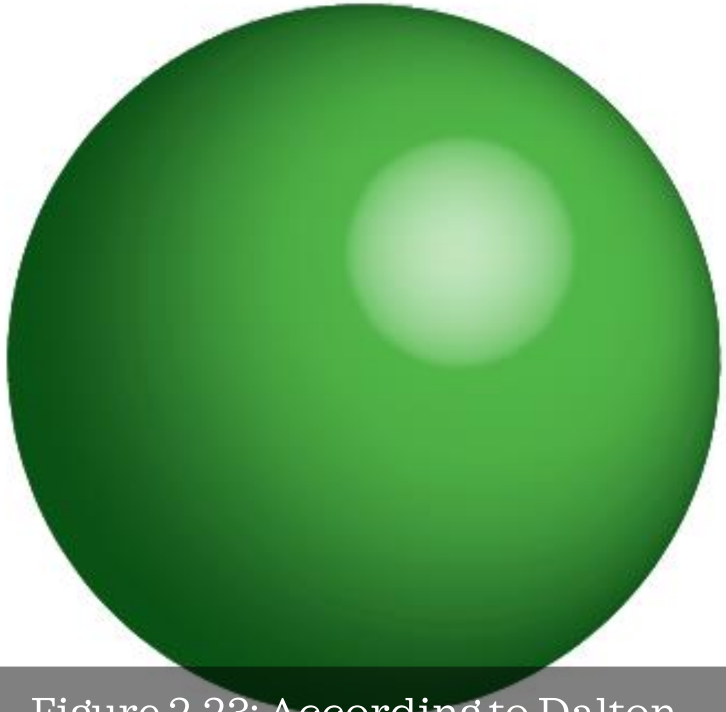


Figure 2.23: According to Dalton, atoms were solid, indestructible spheres.

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

Dalton's Theory of the Atom

3. 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.

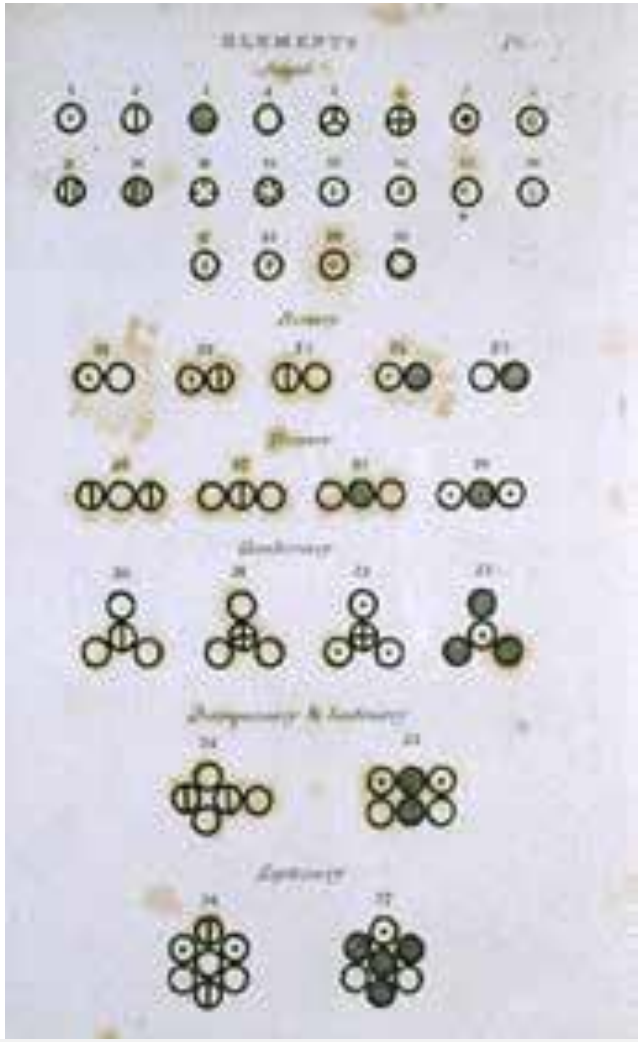
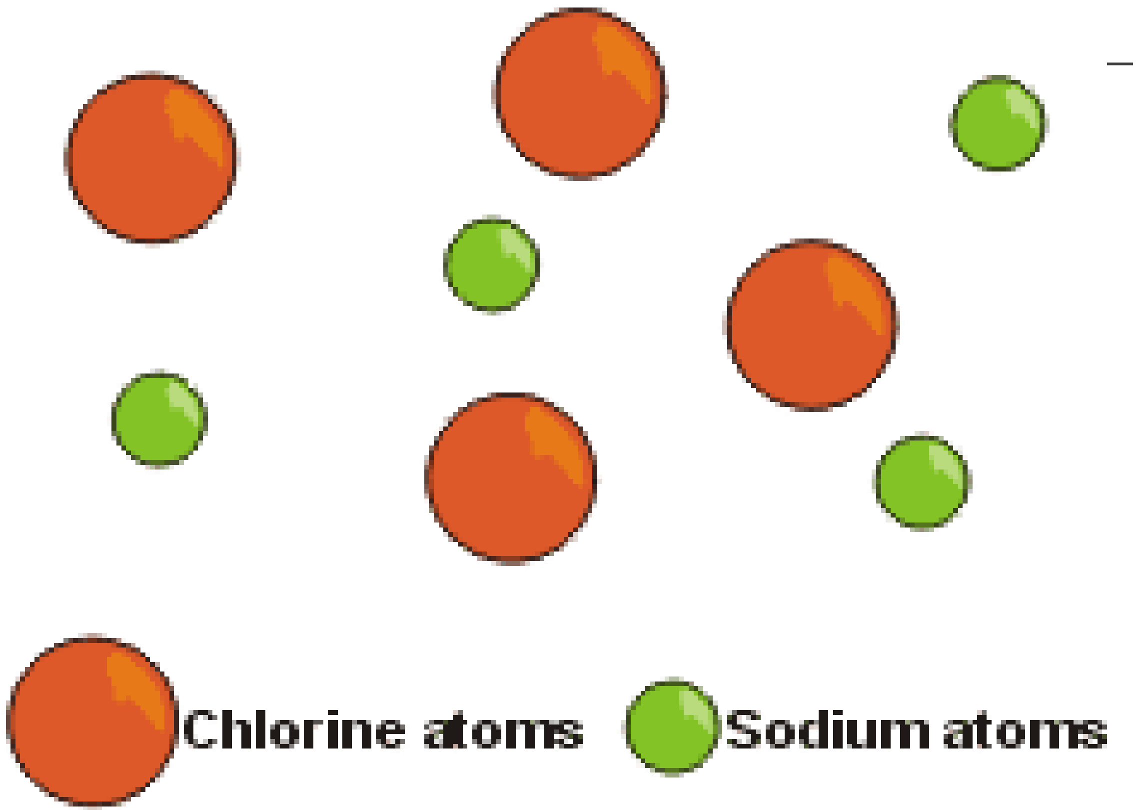
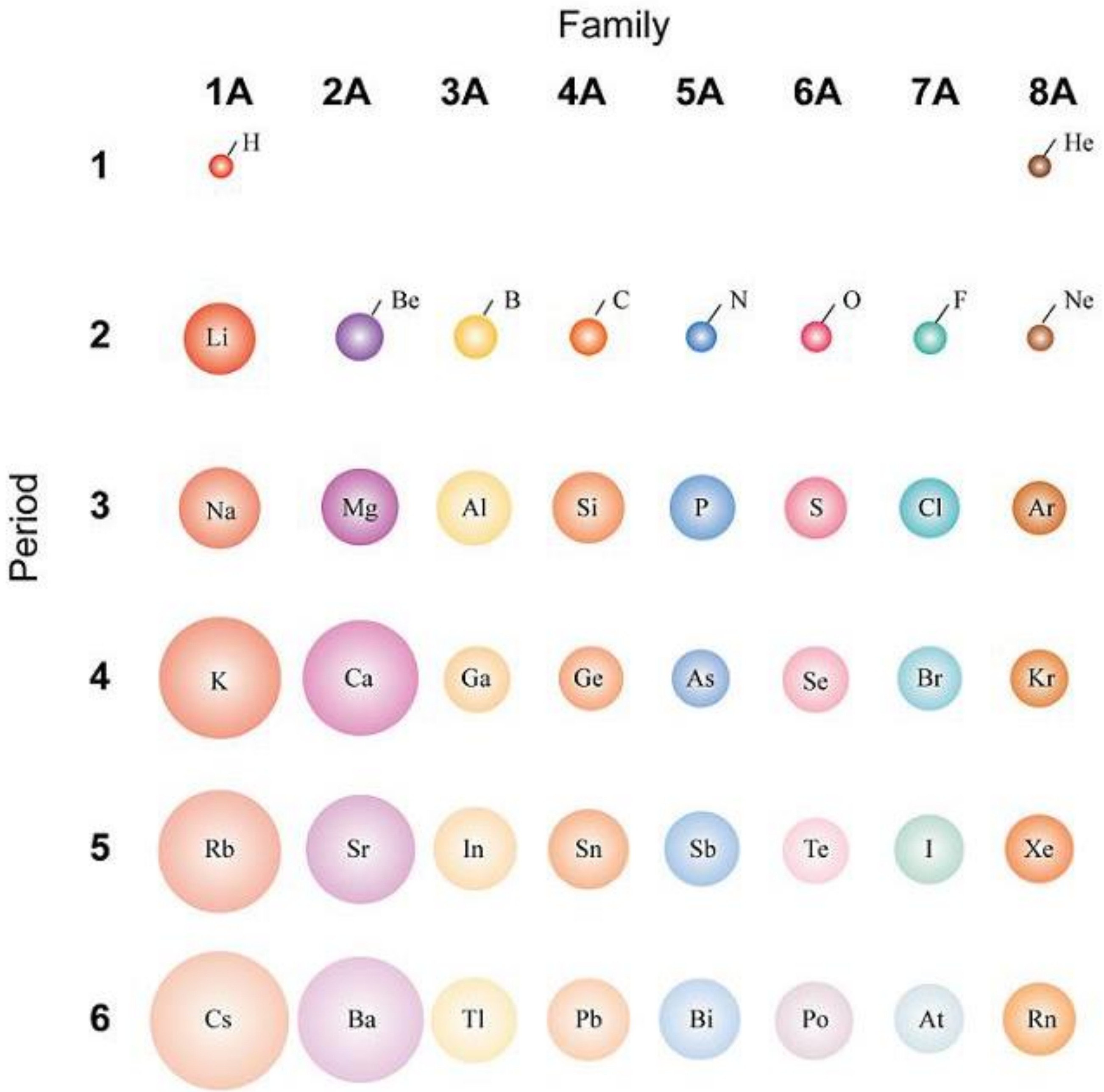


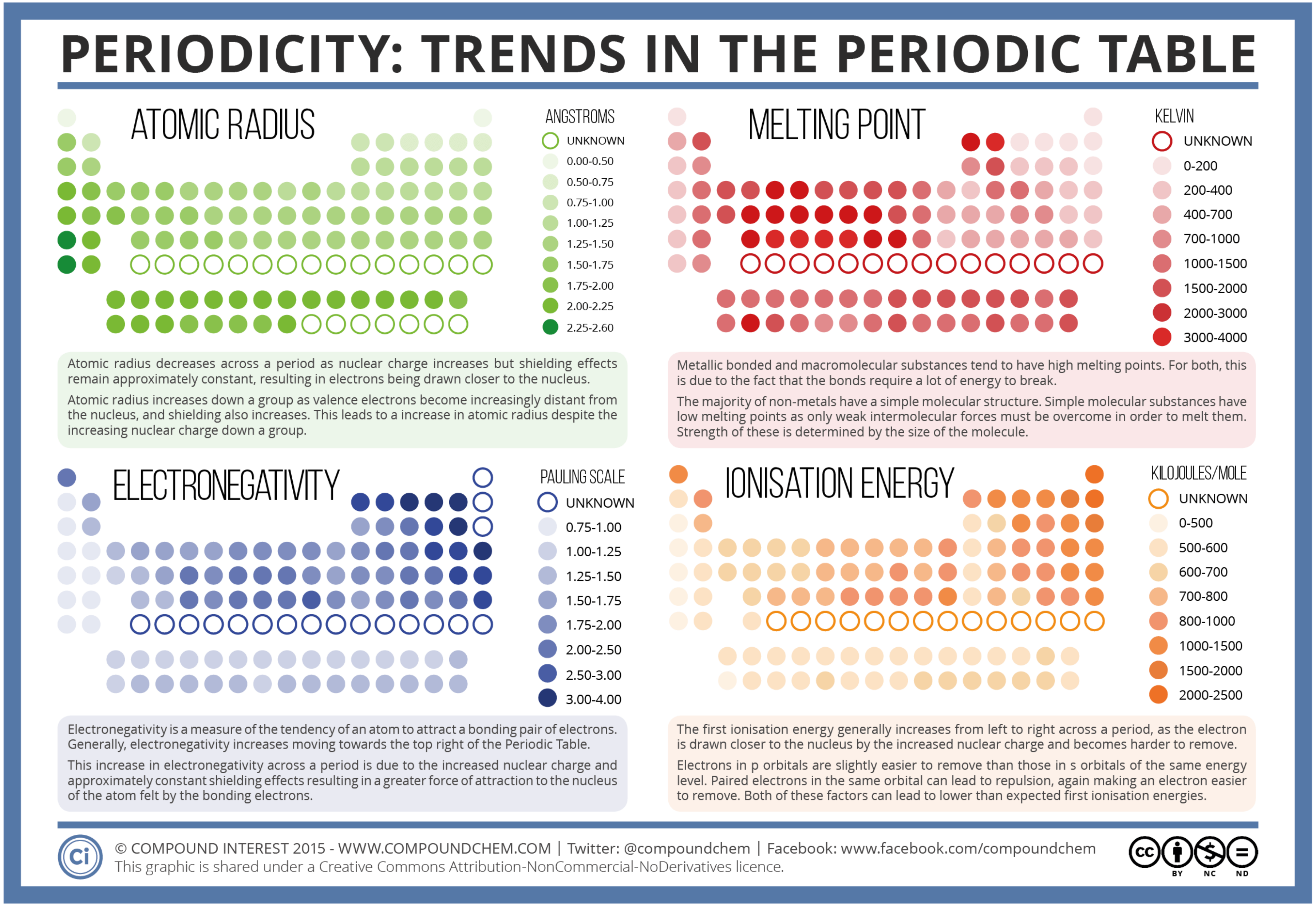
Figure 2.23: A page from Dalton's book which shows the symbols he used to represents atoms of different elements.





Concept 1: Dalton developed an early atomic theory.

https://www.oum.ox.ac.uk/thezone/minerals/define/chemical.htm
https://courses.lumenlearning.com/introchem/chapter/atomic-size/



Concept 1: Dalton developed an early atomic theory.

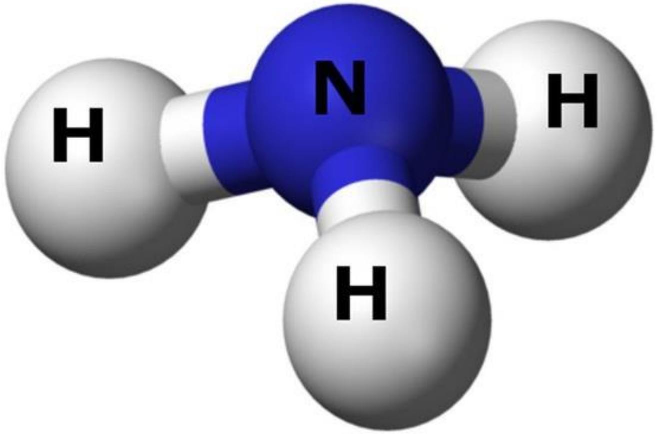
https://www.compoundchem.com/2014/02/12/periodicity-trends-in-the-periodic-table/

Dalton's Theory of the Atom

4. Different atoms combine in simple whole-number ratios to form compounds.

"whole-number ratios": e.g. 1 : 2; 1 : 1; 2 : 3

ammonia: NH_3
(1 nitrogen per 3 hydrogen)



water: H_2O
(2 hydrogen per 1 oxygen)

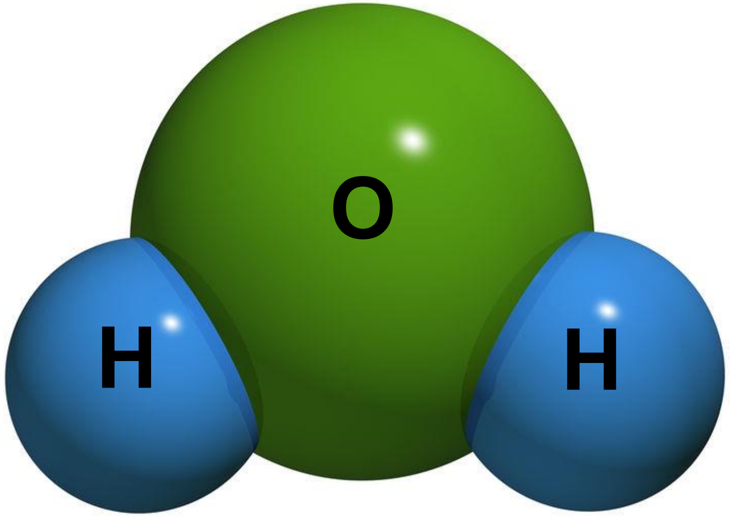
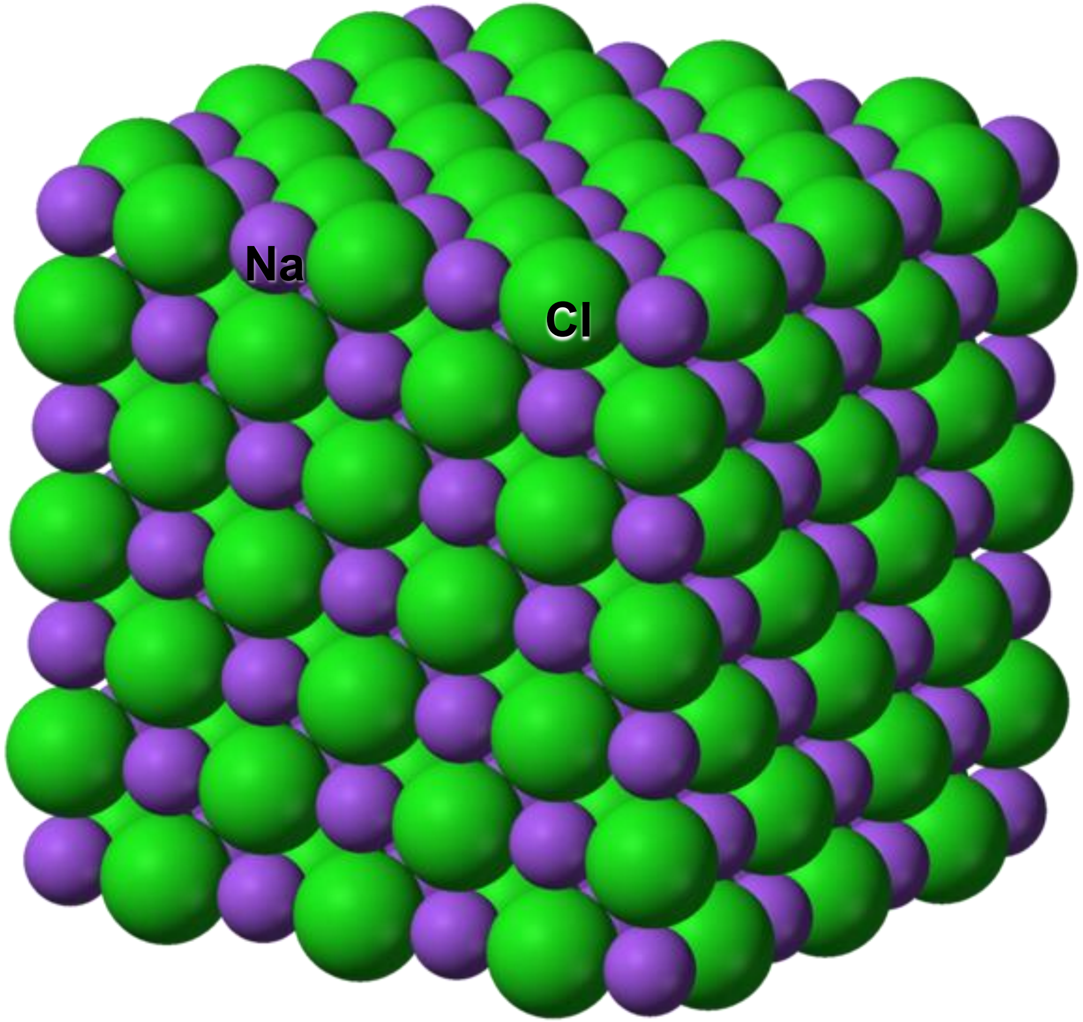


table salt: NaCl (1 sodium per 1 chlorine)



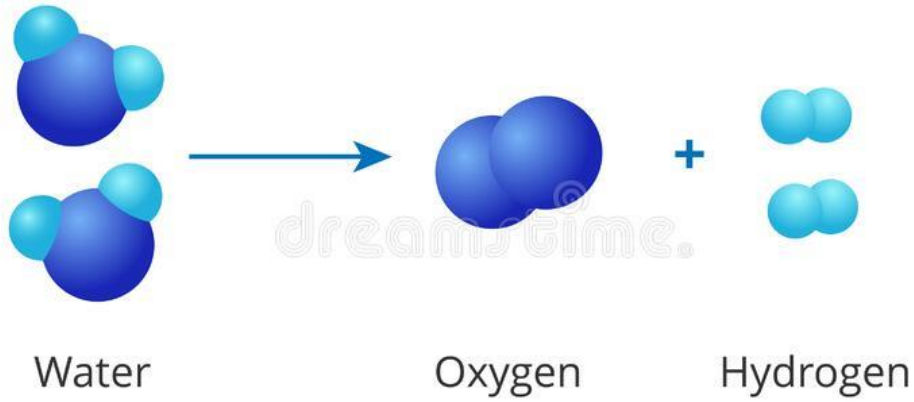
https://www.saddlespace.org/whittakerm/science/cms_page/view/7795103
https://www.quora.com/What-is-the-name-of-the-compound-NH3

Dalton's Theory of the Atom

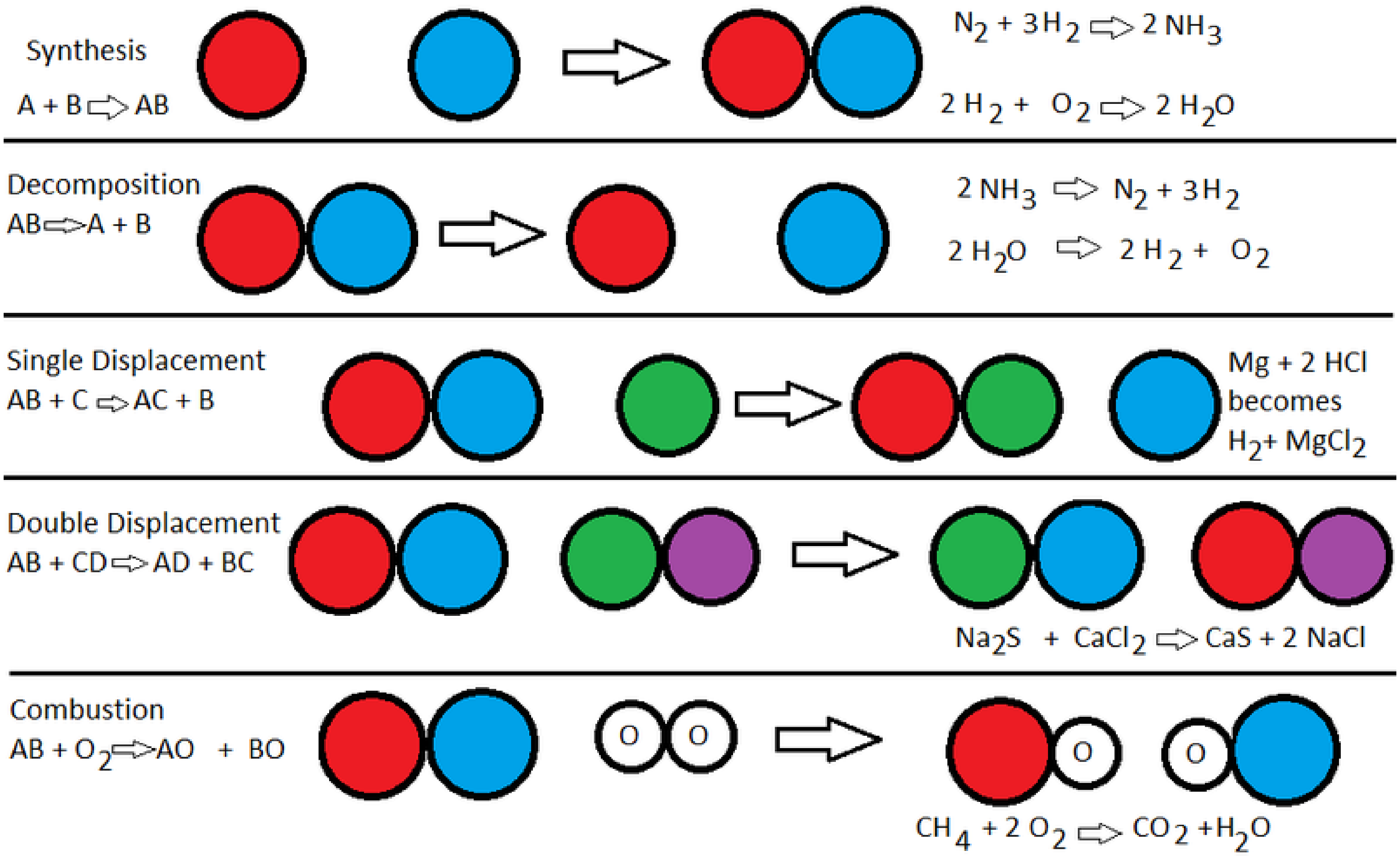
4. Different atoms combine in simple whole-number ratios to form compounds.

"whole-number ratios": e.g. 1 : 2; 1 : 1; 2 : 3

In a chemical reaction, atoms are separated, combined or rearranged.



https://www.dreamstime.com/illustration/decomposition-reaction.html



Study tip: Don't memorize these. Main point is that atoms are rearranged in chemical reactions.

CONCEPT 1: DALTON DEVELOPED AN EARLY ATOMIC THEORY.

https://learnchemisrty.weebly.com/5-types-of-reactions.html

Concept 1: Dalton developed an early atomic theory.

https://www.youtube.com/watch?v=DgsX4E4Ik7Q&feature=emb_title&ab_channel=ScottMilam

CONCEPT 1: DALTON DEVELOPED AN EARLY ATOMIC THEORY.

https://www.youtube.com/watch?v=gbArE5dv0W4&feature=emb_title&ab_channel=SciShow

Discussion Questions

1. Compare and contrast Democritus's *atomos* with Dalton's atomic theory

2. 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

Review/Warm-up

1. What were the 4 main points of Dalton's atomic theory?
2. Why did Dalton receive credit as the father of atomic theory, but not Democritus?
3. Why were Democritus's ideas not initially accepted?

Review/Warm-up

4. Who came up with these ideas first: Democritus or John Dalton?
   a. Matter is made of tiny particles. Dem
   b. Particles of different elements are different in size, mass, and their chemical properties (e.g. how they react) JD
   c. Tiny particles cannot be created, destroyed, or divided. Dem
   d. Tiny particles exist in empty space. Dem
   e. Tiny particles can be combined to form compounds. JD
   f. All particles of the same element are identical. JD

Thomson's Cathode Ray Tube Experiment

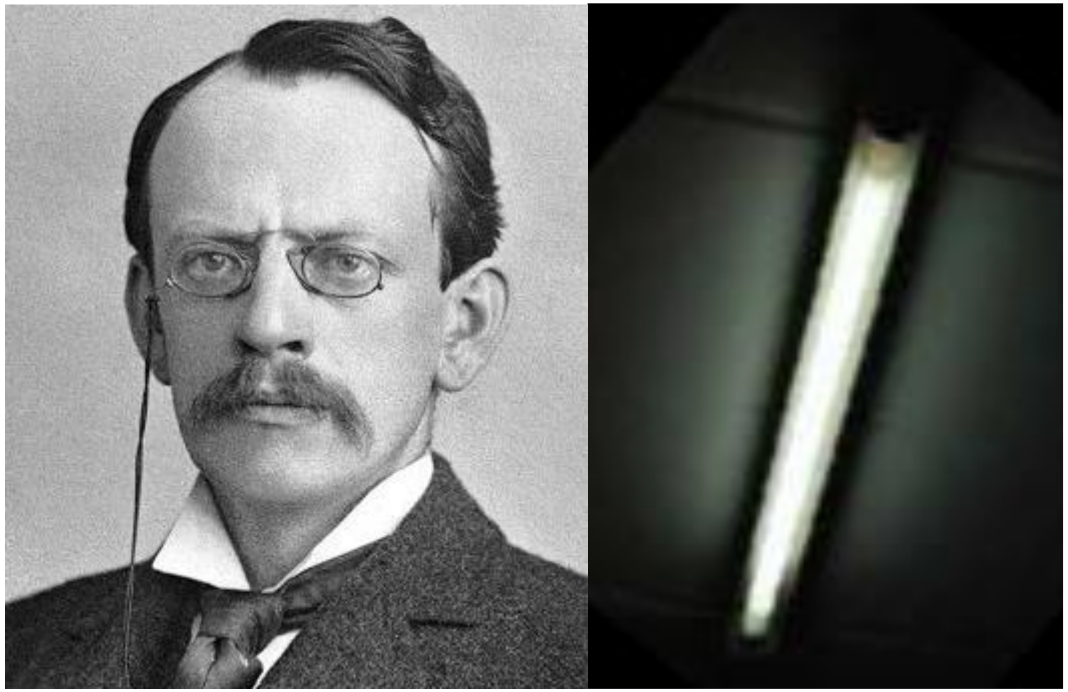


Figure 2.24: Fluorescent lights are examples of cathode ray tubes.

JJ Thomson (1897):

- Studied electric currents in **cathode ray tube**
- When a battery is attached, a cathode ray travels through the tube

His question:

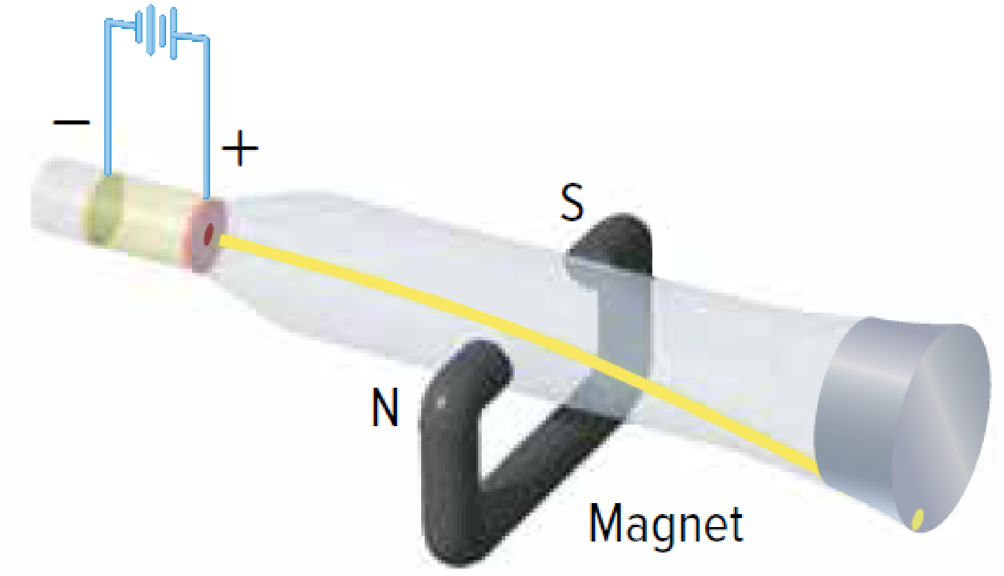
What is a cathode ray?

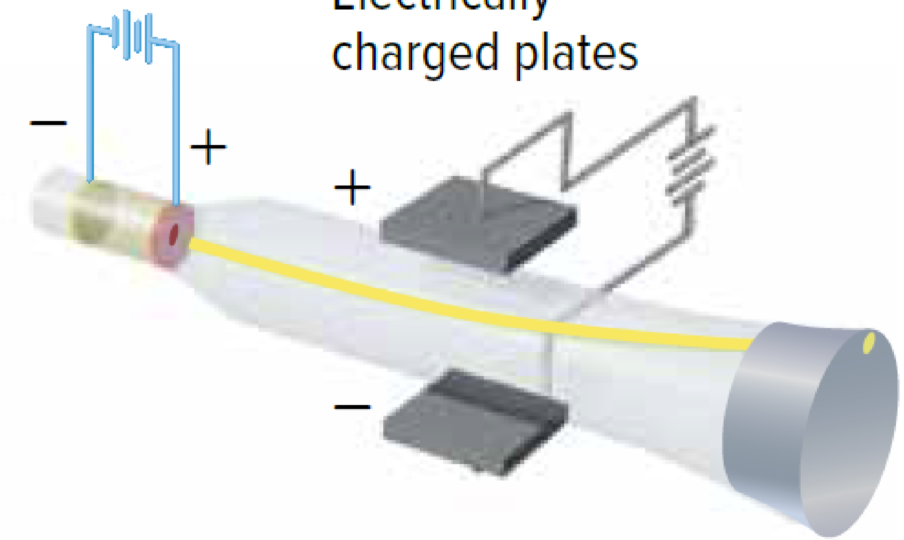
Study tip: No need to memorize dates/years. But you should be able to put the scientists in order.

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:

Cathode rays are streams of negatively charged particles called **electrons.**

- Mass of electron is less than mass of hydrogen atom.
- Atoms ***are divisible***. (Dalton was wrong! → revise atomic theory)

All substances contain electrons.

Thomson's Contribution to Atomic Theory

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

Figure 2.25: Thomson's model of the atom.

Thomson's Model of the Atom

Plum pudding (blueberry muffin) model:

- Positively charged ball with negatively charged electrons embedded

https://www.eatingonadime.com/blueberry-muffin-recipe/
http://blog.wellcomelibrary.org/2016/12/last-minute-plum-pudding/

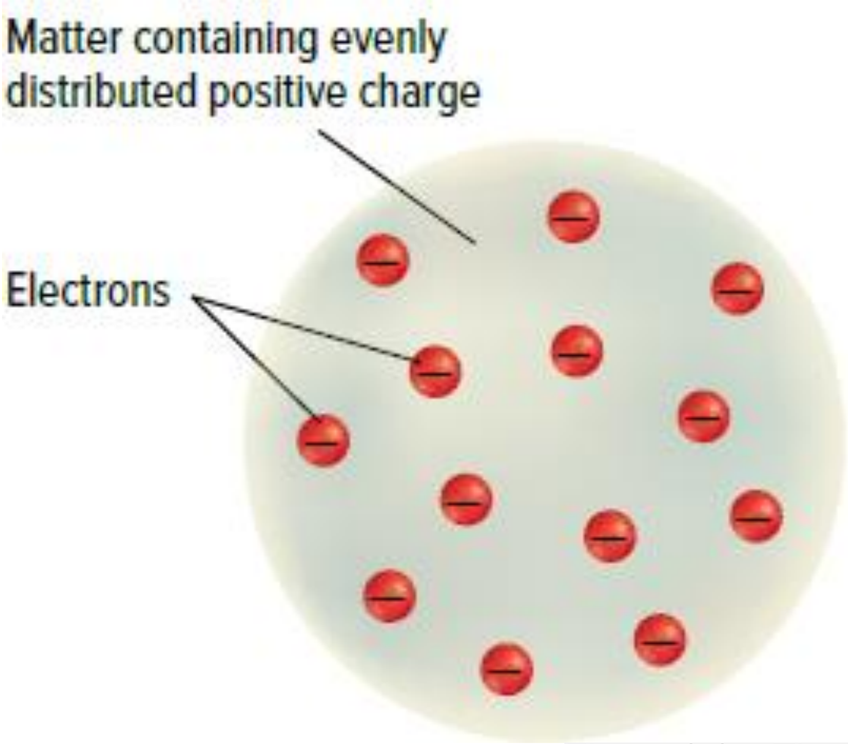
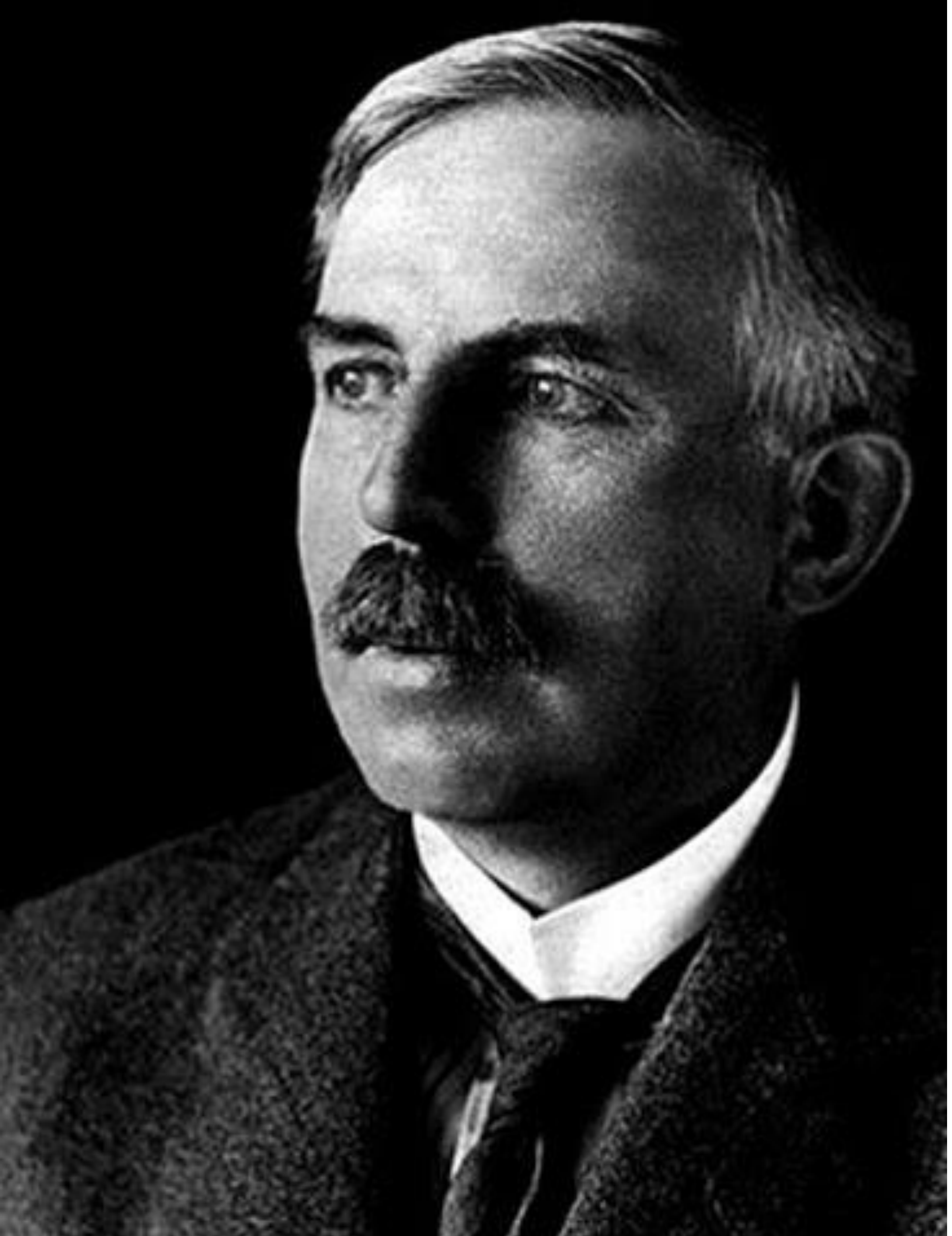


Figure 2.25: Thomson's model of the atom.



http://www.planet-science.com/categories/over-11s/science-celebrities/2011/06/ernest-rutherford-1871%E2%80%931937.aspx

Ernest Rutherford

- Designed gold foil experiment to find out more about the structure of the atom
- (Rationale: if you toss things at atoms, you can figure things out based on how they bounce back.)

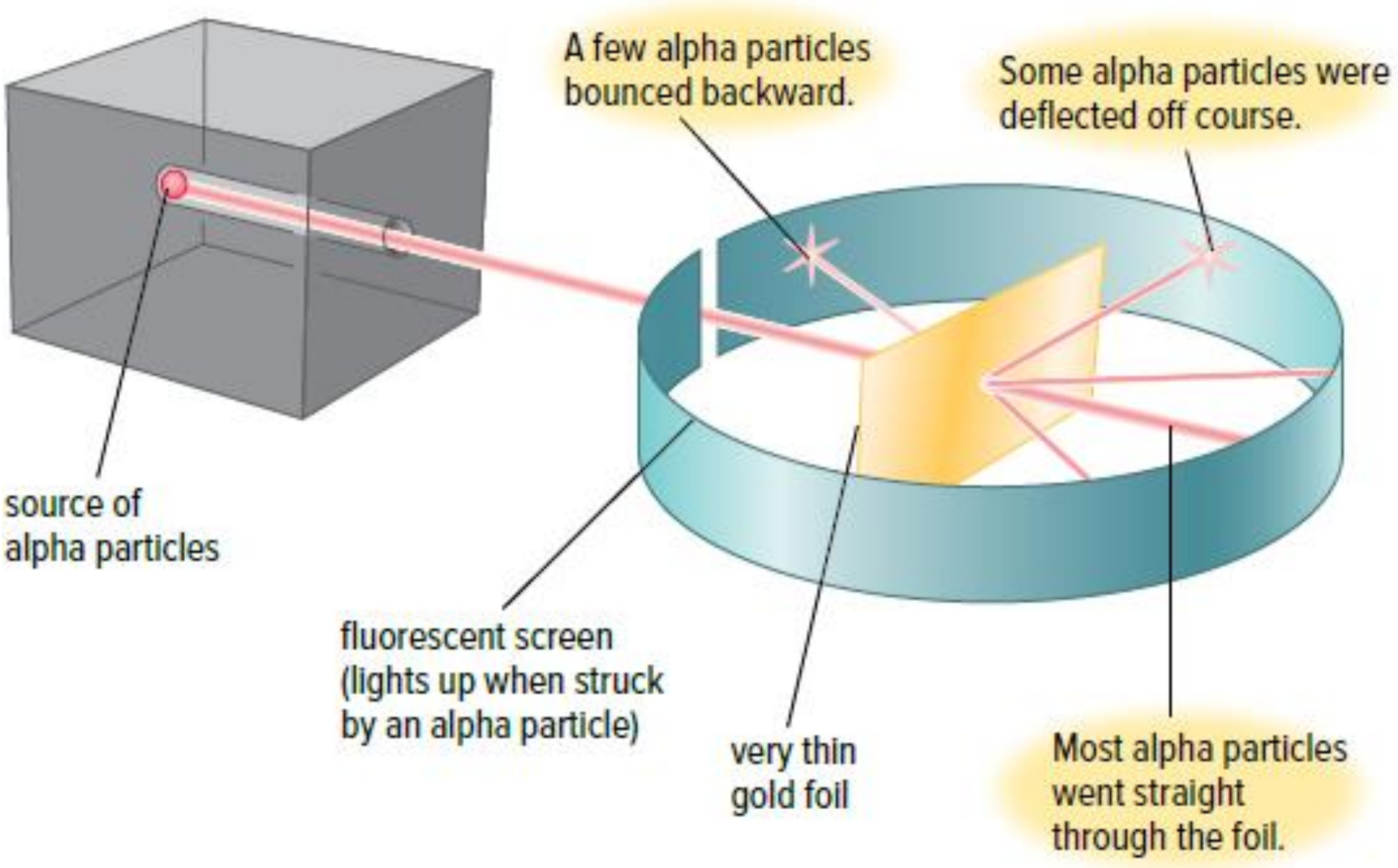


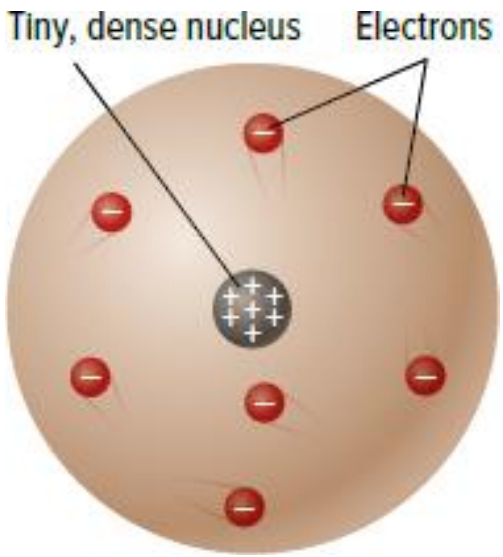
Figure 2.26: In Rutherford's experiment, most of the alpha particles went straight through the foil. But a few bounced back.

Rutherford's Gold Foil Experiment (1909)

- Shot positively-charged alpha particles at thin sheet of gold
- Most alpha particles went through the gold atoms
- Some alpha particles rebounded from the gold foil

Rutherford's Gold Foil Experiment (1909)

Findings	**Conclusions**



Like charges repel. The alpha particles were positively charged. Therefore, the nucleus must also be positive.

Dissecting the Nucleus

Ernest Rutherford and James Chadwick (1920):

- Discovered that the nucleus contains positively charged particles (**protons**) and neutral particles (**neutrons**)

Rutherford and Chadwick's Model of the Atom

Atom has a small, dense, positively charged nucleus. Nucleus contains:

- Protons (positively charged)
- Neutrons (no charge)

Most of the atom's volume is empty space. Electrons move freely in this space.

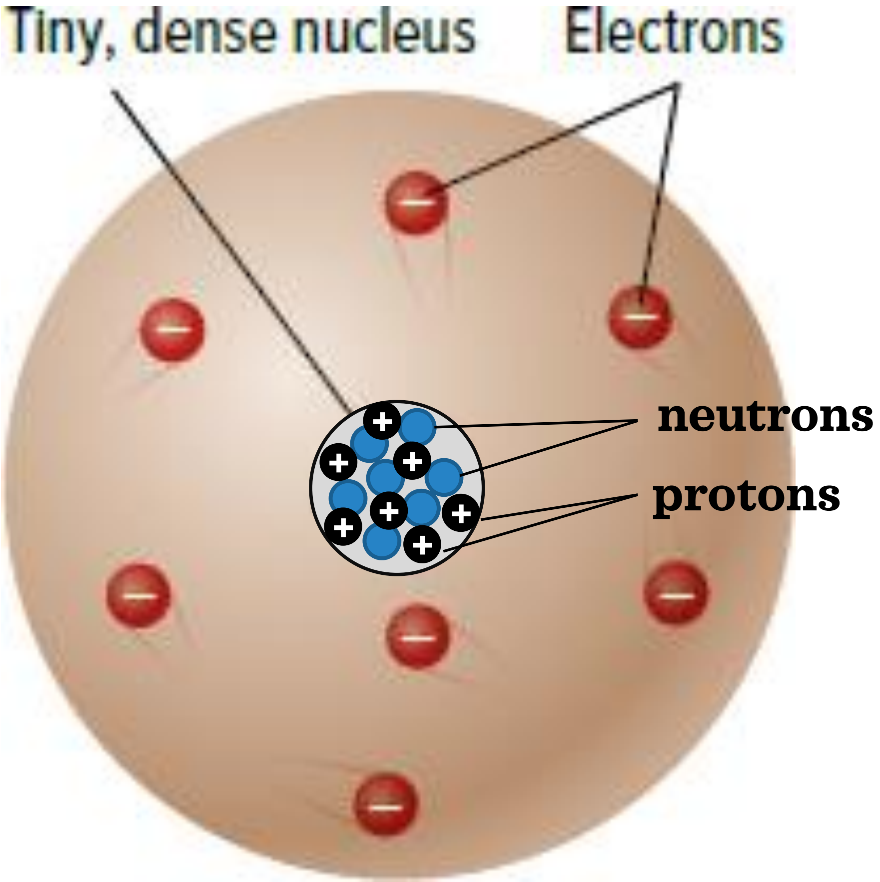


Figure 2.27: Rutherford's revised model of the atom.


24
LIGHT

Niels Bohr (1913)

- Running electricity through gas produces a line spectrum of light; different gases produce different line spectra
- The colour of light emitted by gases is due to high-energy electrons releasing energy
- Different colours of light have different energies; electrons can have only certain allowed energies.

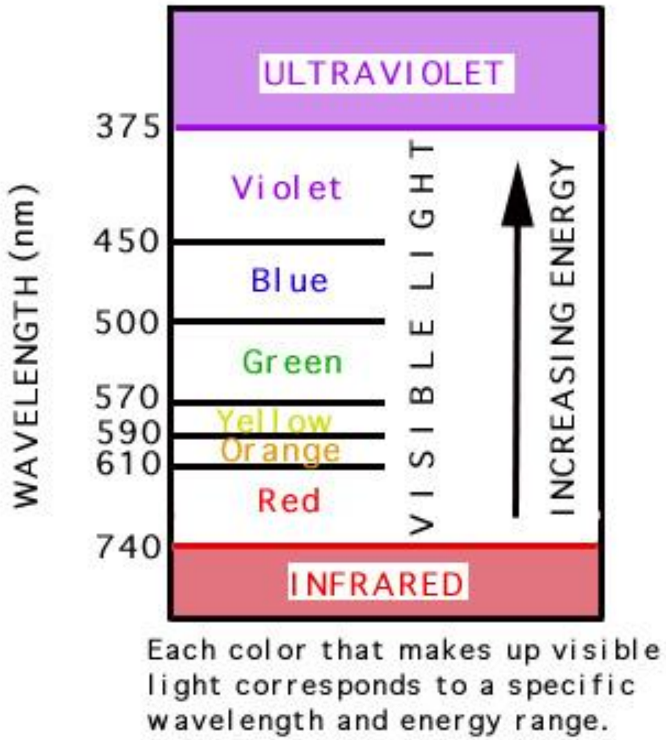
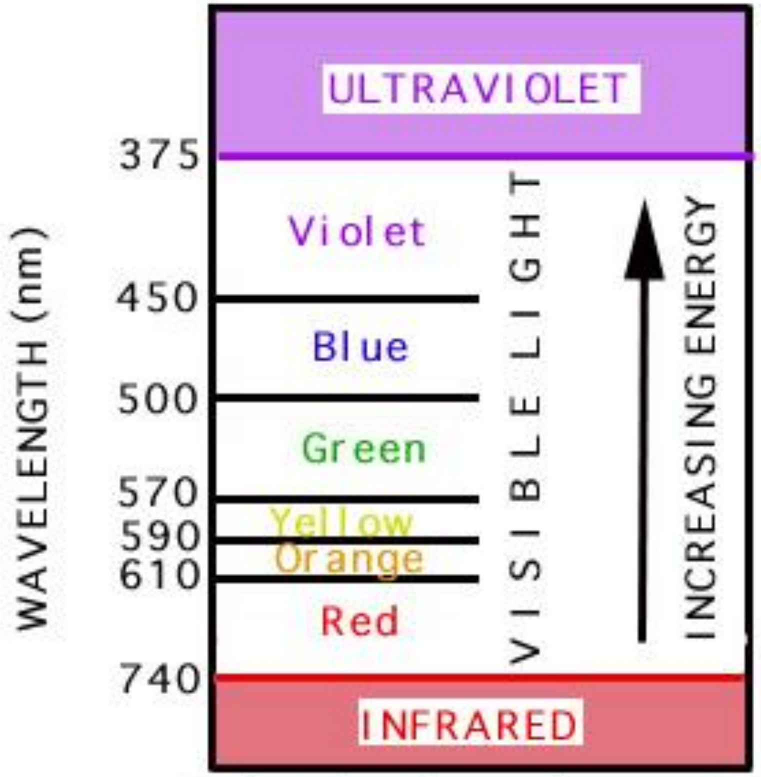


Figure 2.28: The line spectrum for hydrogen provides evidence that electrons can have only certain allowed energies.

Niels Bohr and Emission Spectra (1913)

Background info: Light is a form of energy. Different colours of light have different energies.

Interpret the figure on the right. What colour light has the highest energy? Lowest?

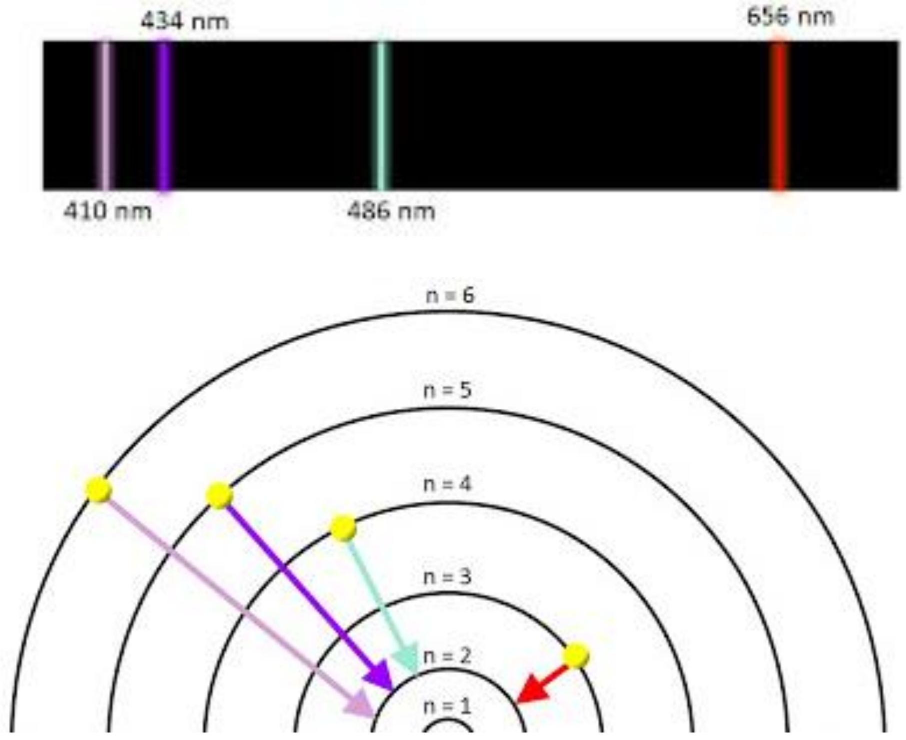


Each color that makes up visible light corresponds to a specific wavelength and energy range.

Niels Bohr and Emission Spectra (1913)

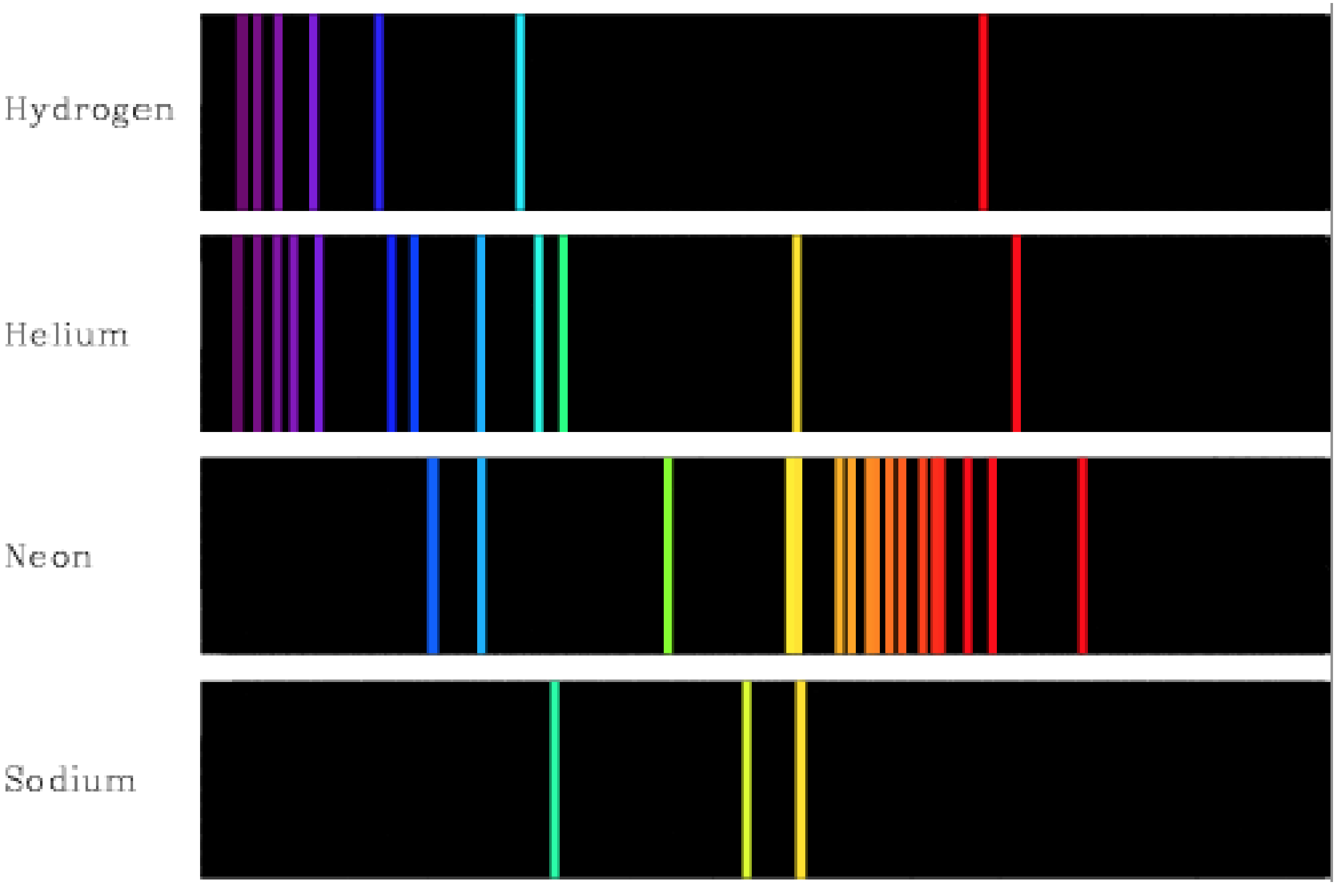
- When electricity is added to gas, electrons of atoms gain energy and jump to higher energy levels
- When electrons fall back down to lower energy levels, they release energy as light of a specific colour. These are the **line spectra** that are observed.

Line Spectrum Example



Niels Bohr and Emission Spectra (1913)

- All elements are slightly different. They have different energy shells and thus different line spectra.



Study tip: When you read/review, make connections to other things you know and have already learned. The more connections you make, the better you will remember things.

> *E.g. when you read "all elements are slightly different" you should be thinking "where have I heard something like this before?", then go back in your textbook. Ah, Dalton was the first to come up with this concept.*

Niels Bohr and Emission Spectra (1913)

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

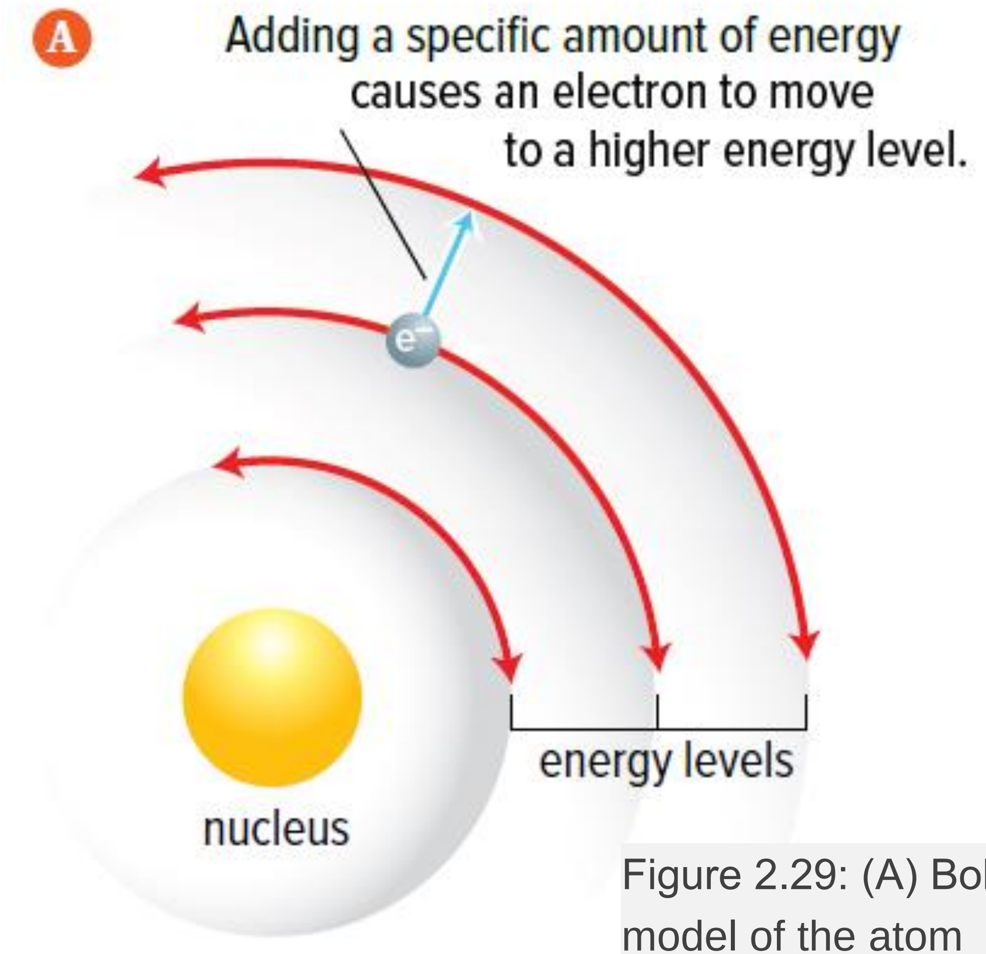
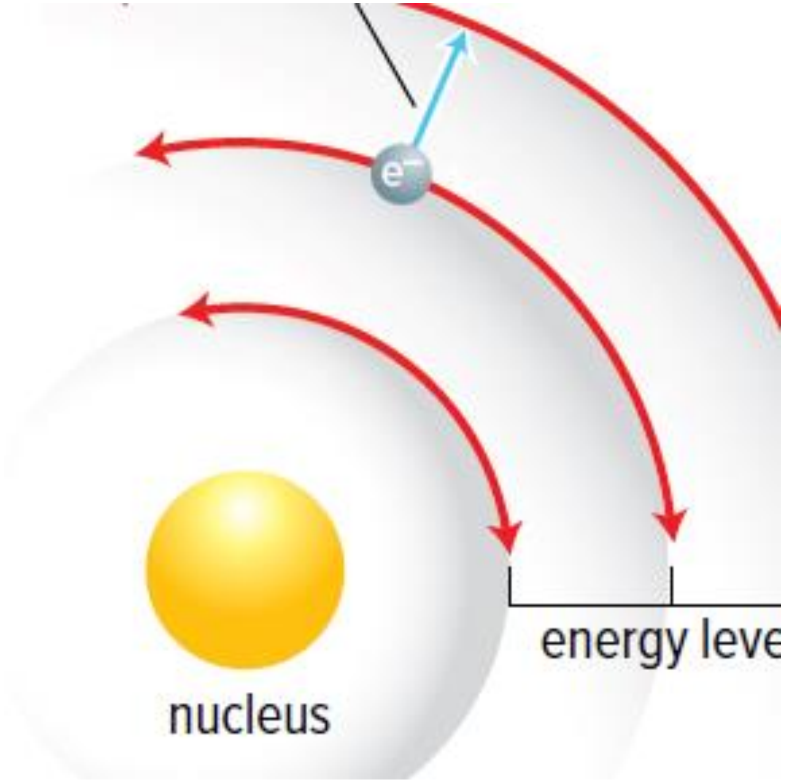


Figure 2.29: (A) Bohr's model of the atom



Discussion Questions

1. Compare and contrast models of the atom.

2. 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**

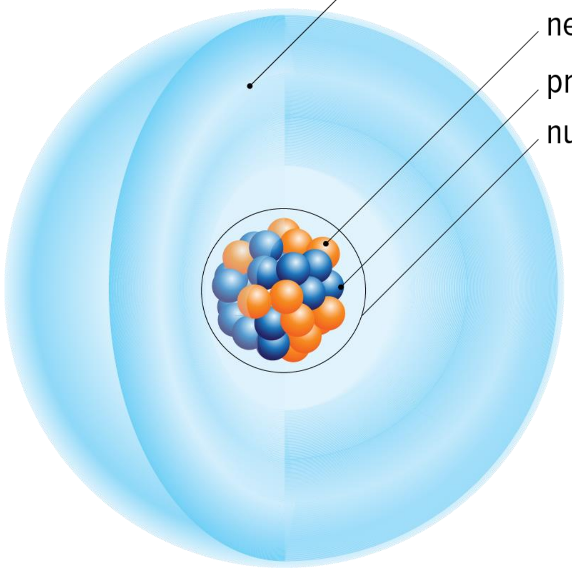


Figure 2.31: Model of the atom.

Nucleus

- Tiny region at the centre of the atom
- Contains protons (+) and neutrons (0 charge)
- Number of protons determines charge of the nucleus and the identity of an atom

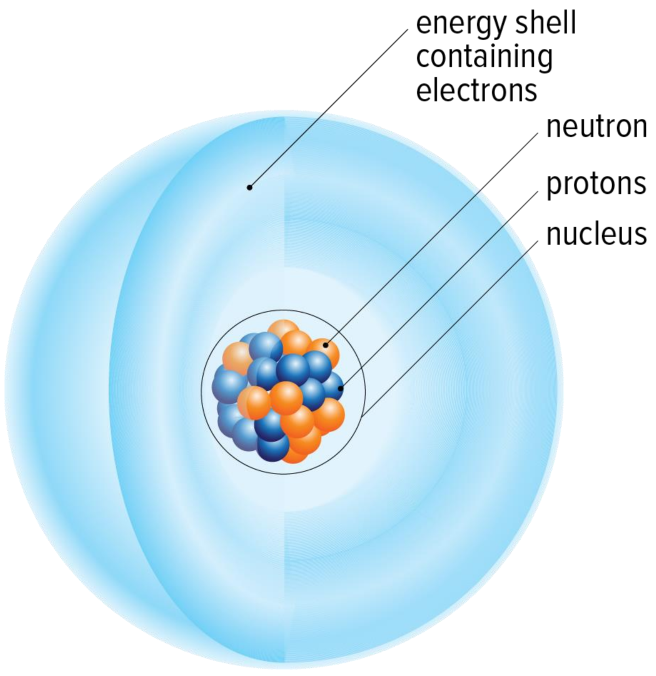


Figure 2.31: Model of the atom.

Electron Energy Shells

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

What model does this 'spread out cloud of charge' remind you of? How are they different?

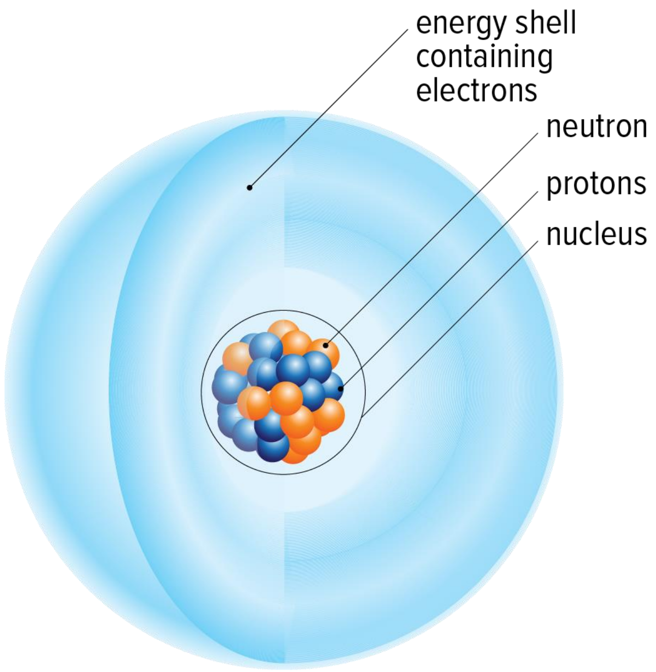


Figure 2.31: Model of the atom.

Electric Charge in the Atom

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 attracts electrons (opposites attract)

Overall charge of an atom: uncharged/neutral (equal numbers of protons and electrons)

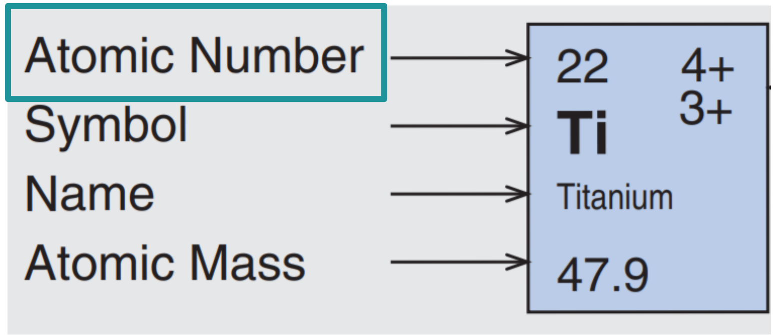
Subatomic Particle Calculations

Recap:

- Number of protons determines charge of the nucleus and the identity of an atom.
- Atoms are neutral: they have equal numbers of protons and electrons.

Subatomic Particle Calculations

The **atomic number** of an element tells us how many **protons** are in an atom of that element.



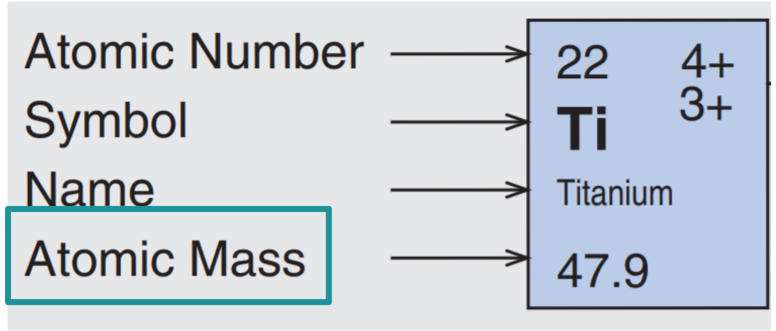
In a neutral atom, there are equal numbers of protons and electrons.

Therefore, in a **neutral atom**,

atomic number = # protons = # electrons

Subatomic Particle Calculations

Basically, the **atomic mass** tells us how many particles are in the atom's nucleus.



Since we already know how many protons there are, we can calculate the number of neutrons.

neutrons = *rounded* atomic mass minus atomic number

If the tenths place is a 4 or lower, round down.	**32.1 → 32**	**65.4 → 65**
If the tenths place is a 5 or higher, round up.	**10.8 → 11**	**35.5 → 36**

Subatomic Particle Summary

Particle	Symbols	Electric Charge	Relative Mass	Location in Atom	How to Calculate?
Proton	p^+, p	1+	1836	Nucleus	= atomic number
Neutron	n^0, n	0	1837	Nucleus	= *rounded* atomic mass minus atomic number
Electron	e^-, e	1-	1	Surrounding the nucleus	= atomic number

Subatomic Particle Calculations

Practice:

Calculate the subatomic particles in the following atoms.

	protons	neutrons	electrons
a) hydrogen	1	0	1
b) boron	5	6	5
c) chlorine	17	19	17
d) magnesium	12	12	12
e) krypton	36	48	36

Size of an Atom

Atoms are incredibly small.

- 2 million (2,000,000) atoms could fit in a millimeter
- 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
- How many atoms are in an adult human?
  - 7×10^{27} atoms

Size of an Atom

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

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

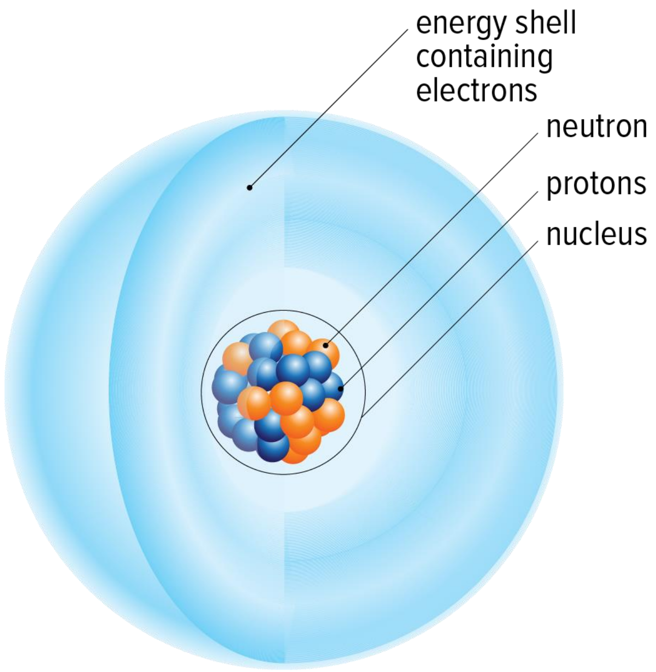


Figure 2.31: Model of the atom.

Discussion Questions

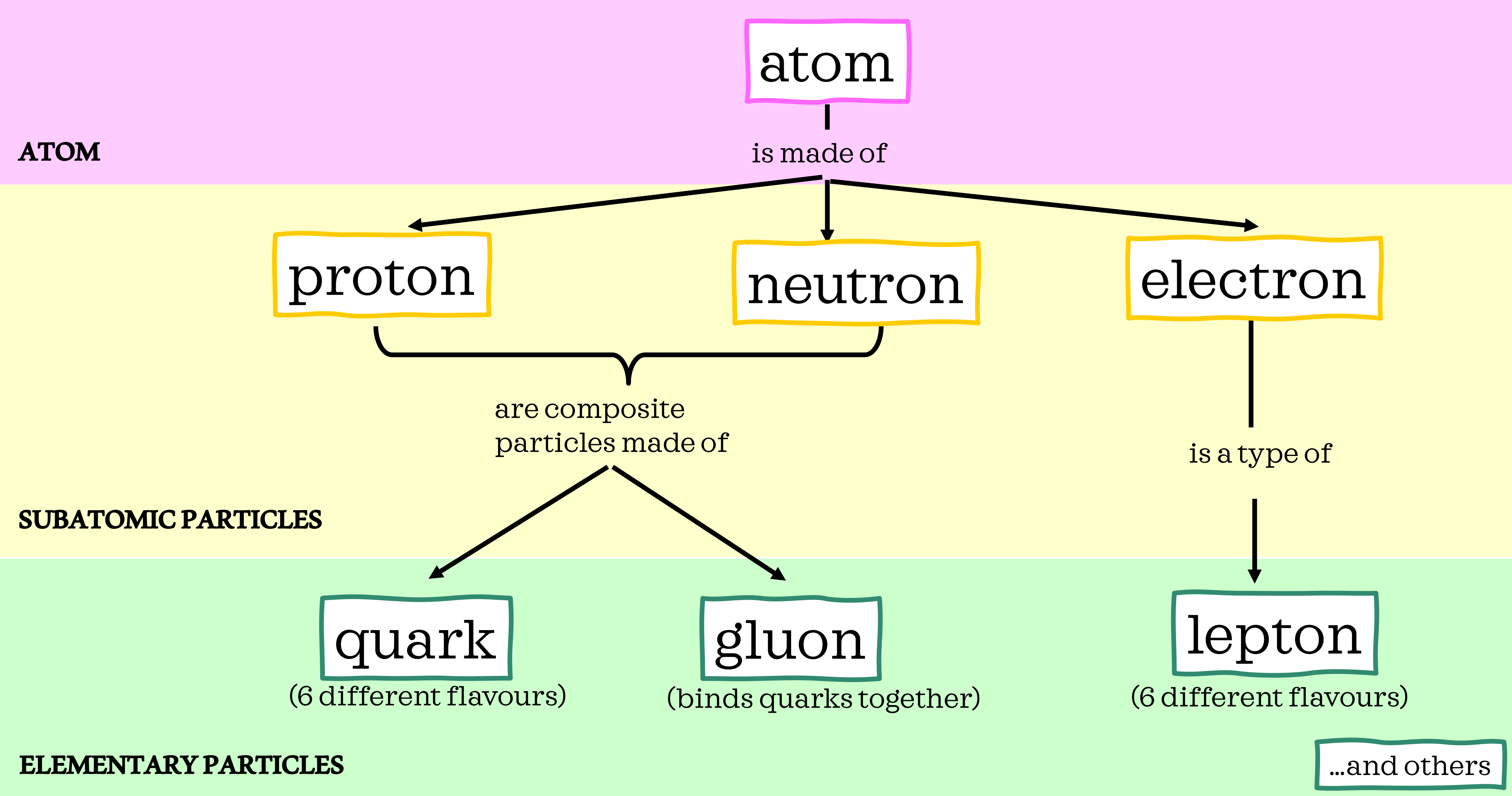
1. What are the three subatomic particles?
2. Compare and contrast the electron and the proton.
3. Use an analogy to describe the size or composition of the atom.
4. What does the existence of a nuclear force explain?

Concept 4: Atomic theory continues to develop.

Surprise! There are even smaller particles than subatomic particles!

Elementary particles cannot be split apart into smaller particles:

- Quarks
- Gluons
- Leptons



CONCEPT 4: ATOMIC THEORY CONTINUES TO DEVELOP.

Leptons

- Do not experience the nuclear force (strong force)
- Come in six "flavours":
  (don't memorize; just know that ***electrons*** are a type of lepton)

Lepton	Description
electron	• 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.
muon	
tau	
electron neutrinos	• 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.
muon neutrinos	
tau neutrinos	

Composite Particles

Composite particles are made of elementary particles.

e.g. Meson, Baryon

Protons and **neutrons** are composite particles made of **quarks and gluons**.

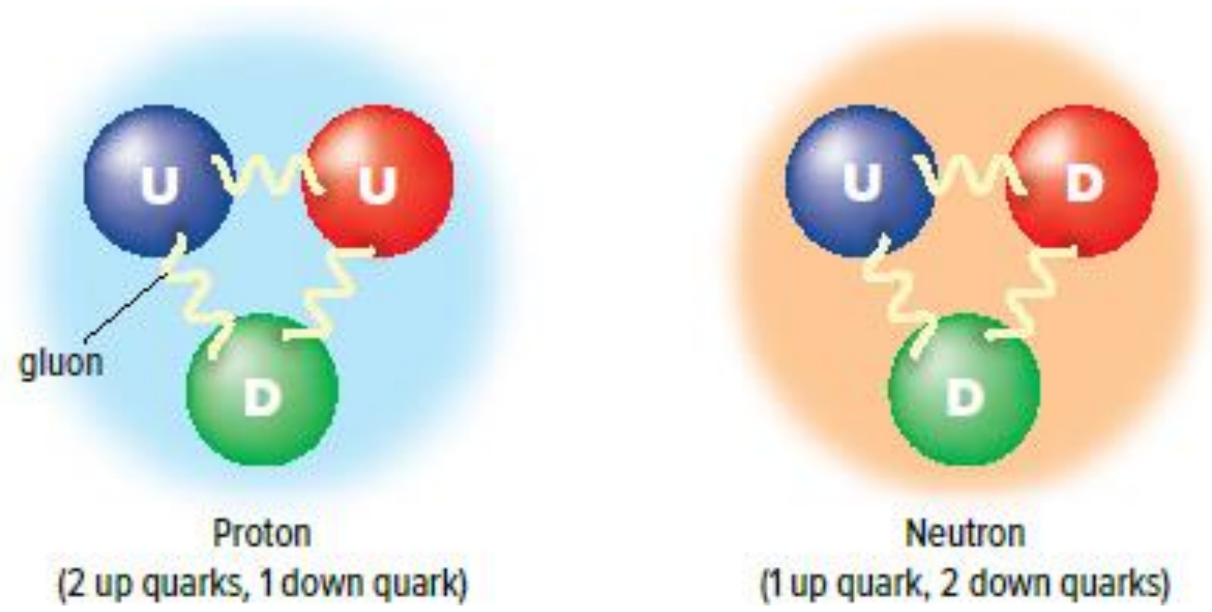


Figure 2.32: Protons and neutrons are made up of smaller elementary particles

Quarks

- Experience the strong force (nuclear force)
- Six different "flavours" of quark (don't memorize):

FYI only. Do not memorize.

Standard Model of Elementary Particles

	three generations of matter (elementary fermions)			three generations of antimatter (elementary antifermions)			interactions / force carriers (elementary bosons)	
	I	II	III	I	II	III		
mass charge spin	≃2.2 MeV/c² ⅔ ½ u **up**	≃1.28 GeV/c² ⅔ ½ c **charm**	≃173.1 GeV/c² ⅔ ½ t **top**	≃2.2 MeV/c² −⅔ ½ ū **antiup**	≃1.28 GeV/c² −⅔ ½ c̄ **anticharm**	≃173.1 GeV/c² −⅔ ½ t̄ **antitop**	0 0 1 g **gluon**	≃124.97 GeV/c² 0 0 H **higgs**
QUARKS	≃4.7 MeV/c² −⅓ ½ d **down**	≃96 MeV/c² −⅓ ½ s **strange**	≃4.18 GeV/c² −⅓ ½ b **bottom**	≃4.7 MeV/c² ⅓ ½ d̄ **antidown**	≃96 MeV/c² ⅓ ½ s̄ **antistrange**	≃4.18 GeV/c² ⅓ ½ b̄ **antibottom**	0 0 1 γ **photon**	SCALAR BOSONS
	≃0.511 MeV/c² −1 ½ e **electron**	≃105.66 MeV/c² −1 ½ μ **muon**	≃1.7768 GeV/c² −1 ½ τ **tau**	≃0.511 MeV/c² 1 ½ e^+ **positron**	≃105.66 MeV/c² 1 ½ $\bar{\mu}$ **antimuon**	≃1.7768 GeV/c² 1 ½ $\bar{\tau}$ **antitau**	≃91.19 GeV/c² 0 1 Z **Z^0 boson**	GAUGE BOSONS VECTOR BOSONS
LEPTONS	<2.2 eV/c² 0 ½ ν_e **electron neutrino**	<0.17 MeV/c² 0 ½ ν_μ **muon neutrino**	<18.2 MeV/c² 0 ½ ν_τ **tau neutrino**	<2.2 eV/c² 0 ½ $\bar{\nu}_e$ **electron antineutrino**	<0.17 MeV/c² 0 ½ $\bar{\nu}_\mu$ **muon antineutrino**	<18.2 MeV/c² 0 ½ $\bar{\nu}_\tau$ **tau antineutrino**	≃80.39 GeV/c² 1 1 W^+ **W^+ boson**	≃80.39 GeV/c² −1 1 W^- **W^- boson**

Mind Map Activity

Make a mind map that summarizes your understanding of the relationships between the following:

- Atom
- Subatomic particles
- Protons
- Electrons
- Neutrons
- Elementary particles
- Composite particles
- Quarks
- Gluons
- Leptons
- Strong force

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

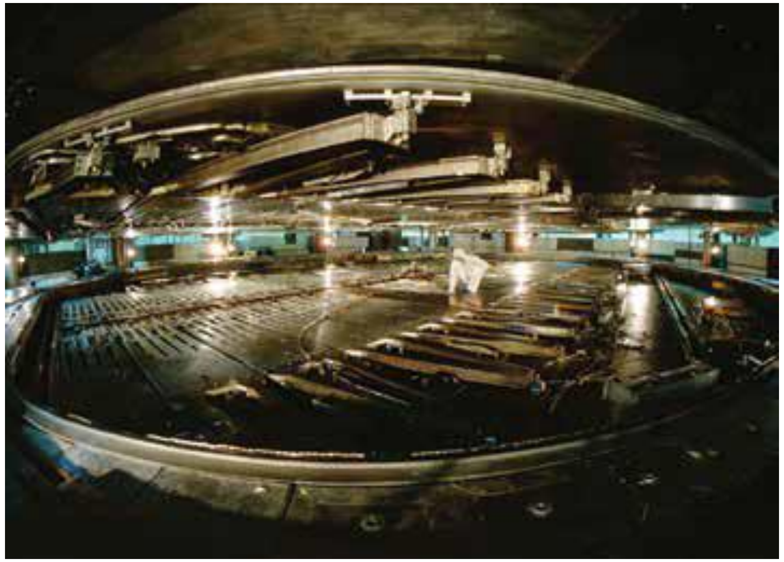
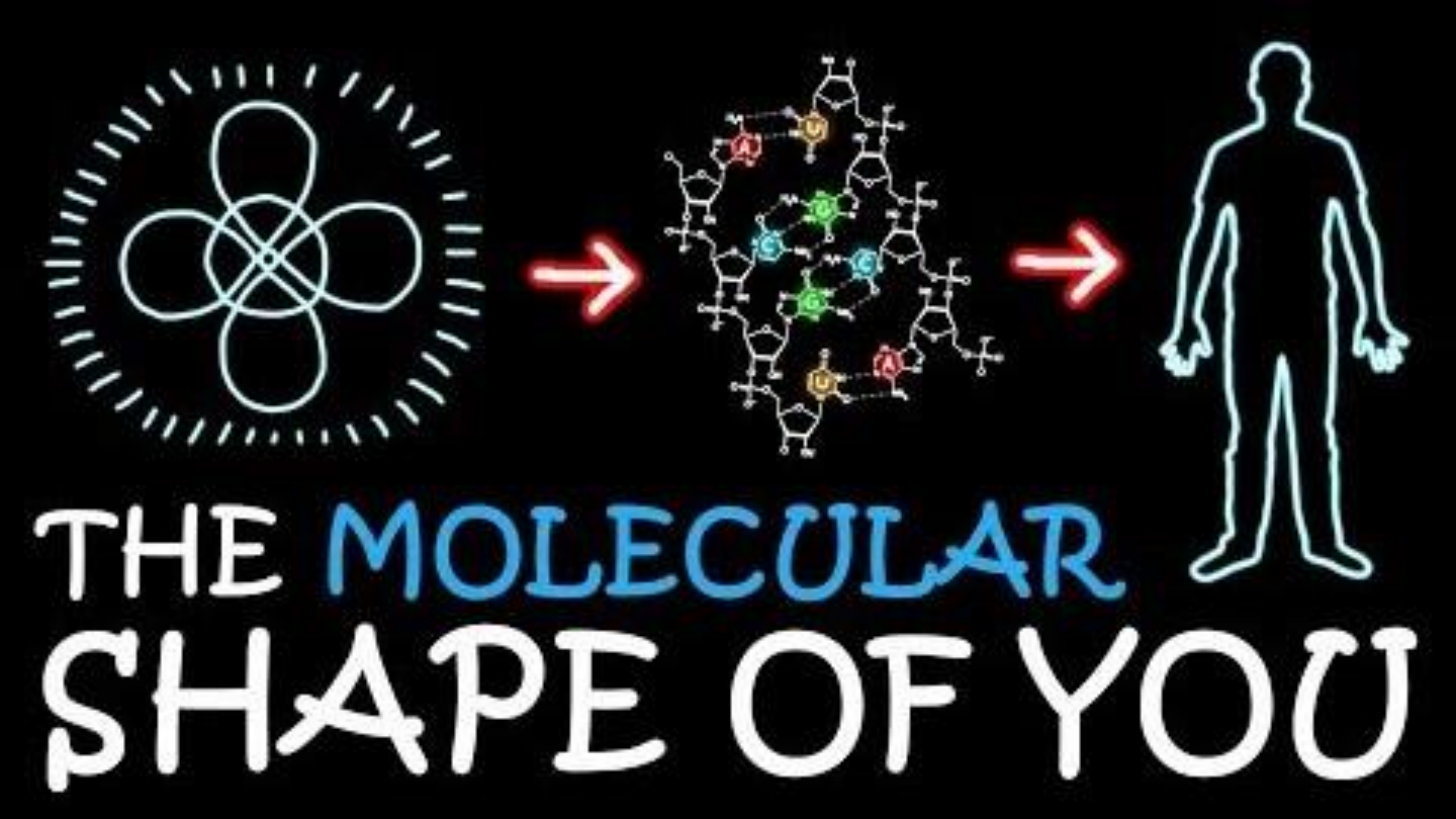


Figure 2.33: The TRIUMF cyclotron.

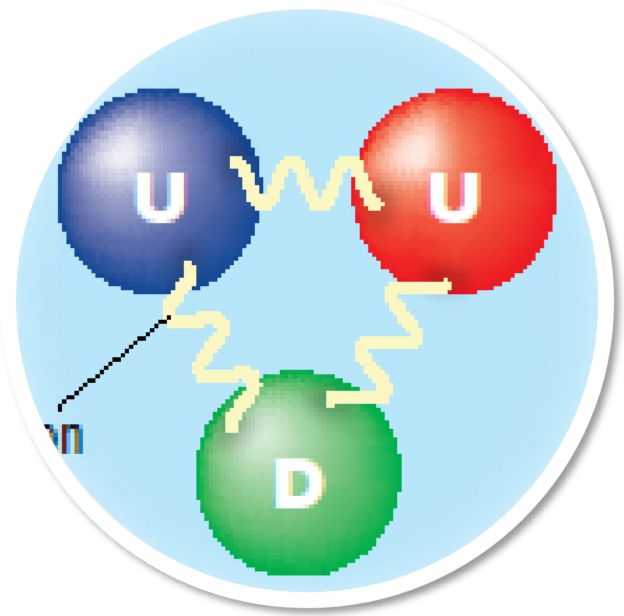
Research Continues: TRIUMF Cyclotron

https://www.youtube.com/watch?v=328pw5Taeg0&ab_channel=Seeker


THE MOLECULAR
SHAPE OF YOU

Discussion Questions

1. Describe the structure of a proton.
2. 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.