Ch. 26~27 History of Modern Physics

Relativity (Einstein 1905, 1915)
Quantum Mechanics (many over 30 years)

AP Physics 2

Fill in the Study Guide

Classical (Newtonian) Mechanics	Modern Physics (2 main parts)

• Slow Motion
 	
• Large Object (Ball)
	1. Near Light Speed (Relativity)
	  • Einstein 1905, 1915
	2. Small Particle (Quantum Mechanics)
	  • Many scientists (30 years)
	  • (charge is quantized, Thomson and e, Rutherford and nucleus)
	  • Energy is quantized (photon E=n hf)
	    • Light is a wave and a particle
	  • Particle as a Wave (Wave-Particle Duality)
	    • Why only certain f? Discrete orbitals (Bohr)
	    • Diffraction/interference effects only apparent for small apertures (deBroglie matter waves)
	    • Matter waves and probability (Schrodinger)
	    • Heisenberg Uncertainty Principle

- Correspondence Principle: Relativistic equations become Newtonian at low speeds

1905: Einstein's Miraculous Year *Annus Mirabilis* Papers

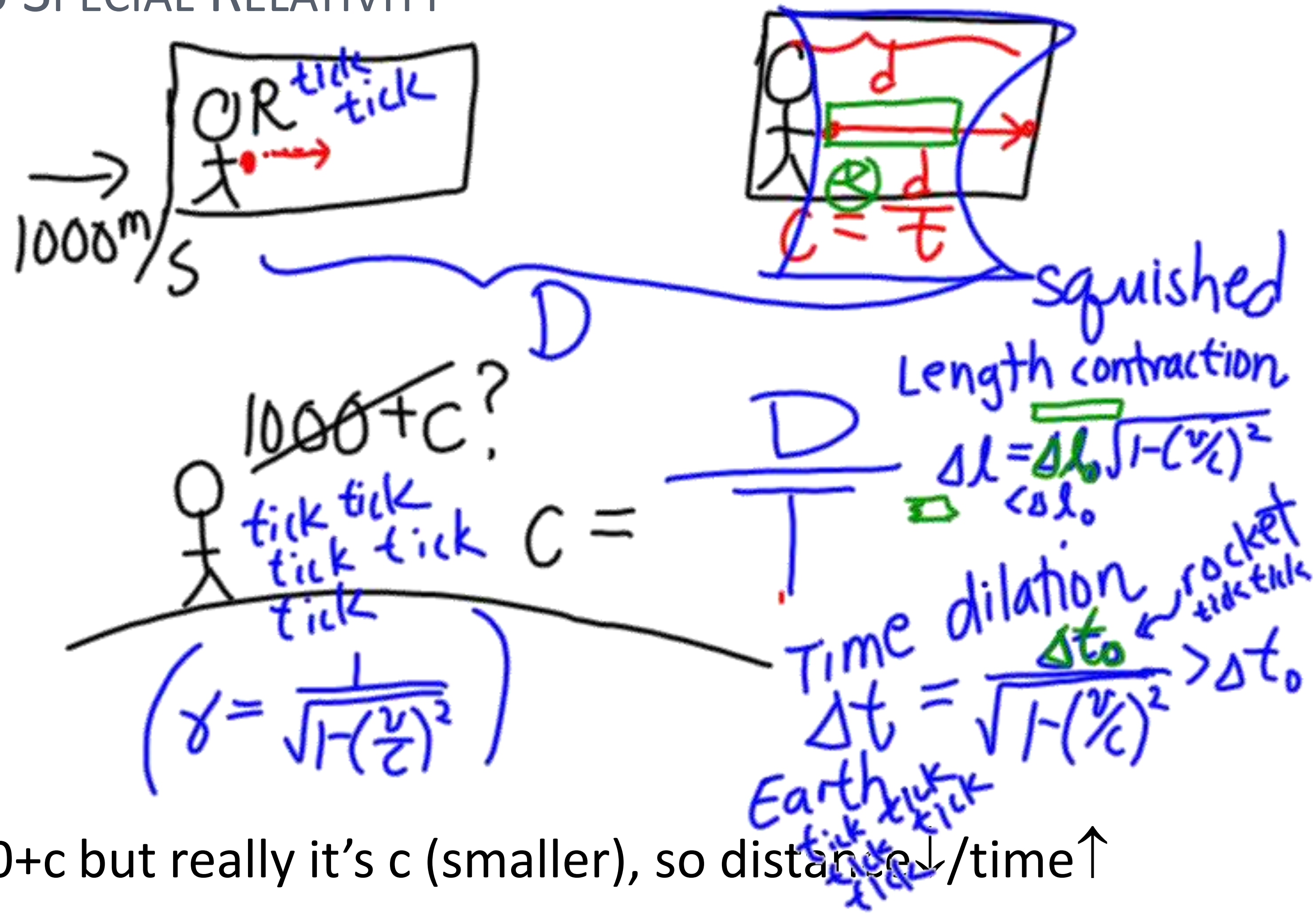
1. Photoelectric Effect (Ch. 27)
   - Nobel Prize
   - Photon, Why energy is quantized. Backbone of quantum mechanics
2. Brownian Motion
   - Pollen grains on surface of water are moving around
   - Evidence for atomic theory
   - Statistical Mechanics explains it
3. Special Relativity (Ch. 26) was not quite accepted until later
   - Inertial (constant velocity) frame of reference. Laws of physics are the same in any inertial frame.
   - The speed of light is the same in all inertial frames
   - There is no ether
4. $E=mc^2$
   - From special relativity equations
   - Fission and fusion (Ch. 30~31)
   - Beginning of General Relativity

- General Relativity (1911, 1916) (Ch. 33-4)
  - Noninertial (accelerating) frame of reference
  - Gravity bends space and time
  - Experimental proof (1919) Eddington. Solar eclipse, could see starlight bend around the Sun. Einstein became a celebrity. Headlines: "Revolution in Science – New Theory of the Universe – Newtonian Ideas Overthrown"

Ch. 26 Special Relativity
Postulates

1. The laws of physics have the same form in all inertial reference frames.
2. Light travels through empty space with the speed c independent of the speed of the source or observer. c is the same in all inertial reference frames.

- Inertial reference frame = one that is moving at constant velocity with respect to a stationary reference (like Earth)
- $c = 3.00 \times 10^8$ m/s
- Weird consequences: speed c is constant, so distance and time must not be absolute!



- 1000+c but really it's c (smaller), so distance↓/time↑
- For a person on Earth looking at the rocket,
  - Time on the rocket passes slower (Earth people age faster)
  - The rocket looks squished

Ch. 26 Special Relativity

- Interstellar: The father goes on a spaceship and returns to Earth. The daughter on Earth ends up older than the father.
- Traveling to the future: Go on a rocket at 0.999c for 4.5 years. Come back to an Earth that changed by 100 years. (Giancoli P. 754)
- Time dilation Experiment: Atomic clock runs slow on an airplane https://www.youtube.com/watch?v=gdRmCqylsME

FIGURE 26–12 Question 14. Mr Tompkins as seen by people on the sidewalk. See also Chapter-Opening Figure on page 744.

Ch. 26 Special Relativity

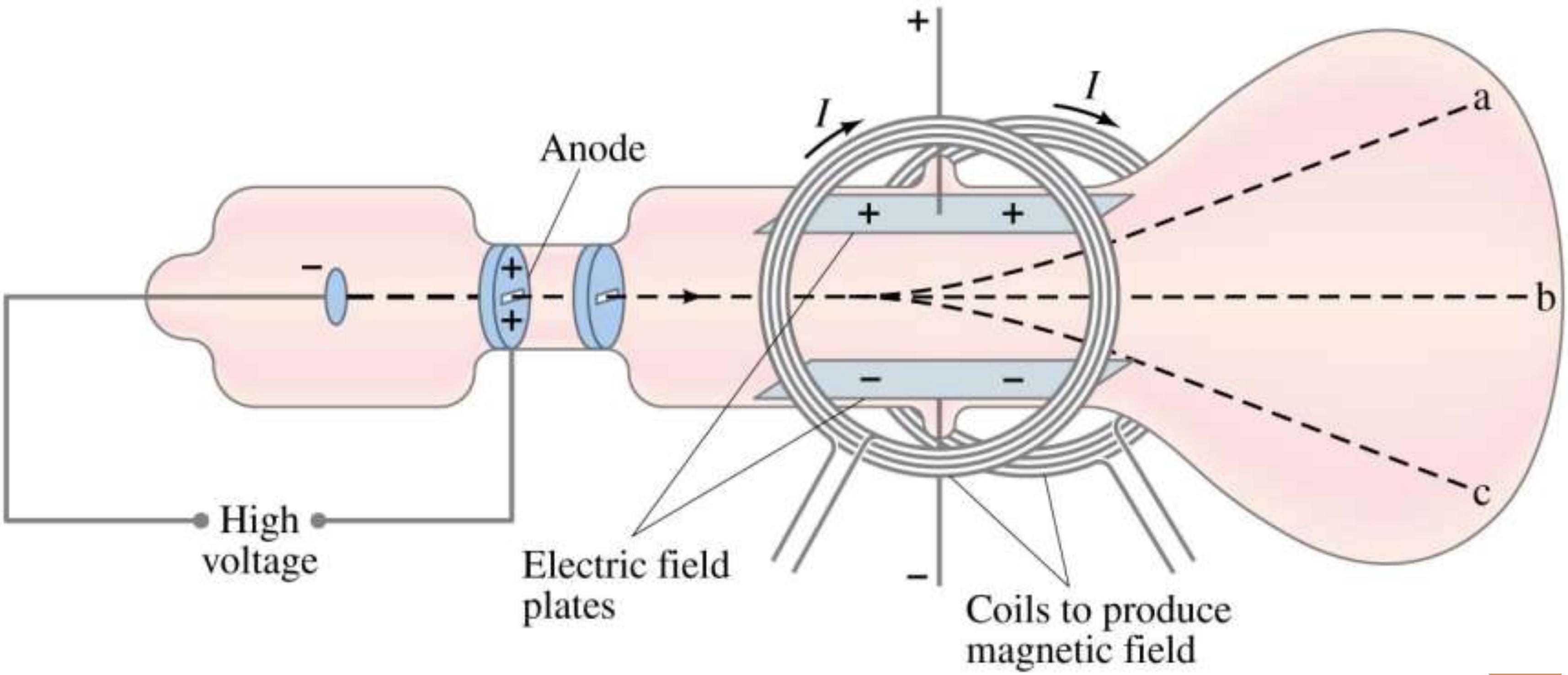
- More to fill in maybe
- See southwest.mpls.k12.mn.us/uploads/hl2_chapter_29_notes.pdf
- 31 history pix
- 30 Compton and deBroglie

Ch. 27 Early Quantum Theory Photon, Photoelectric Effect deBroglie Emission Spectra and Bohr

AP Physics B

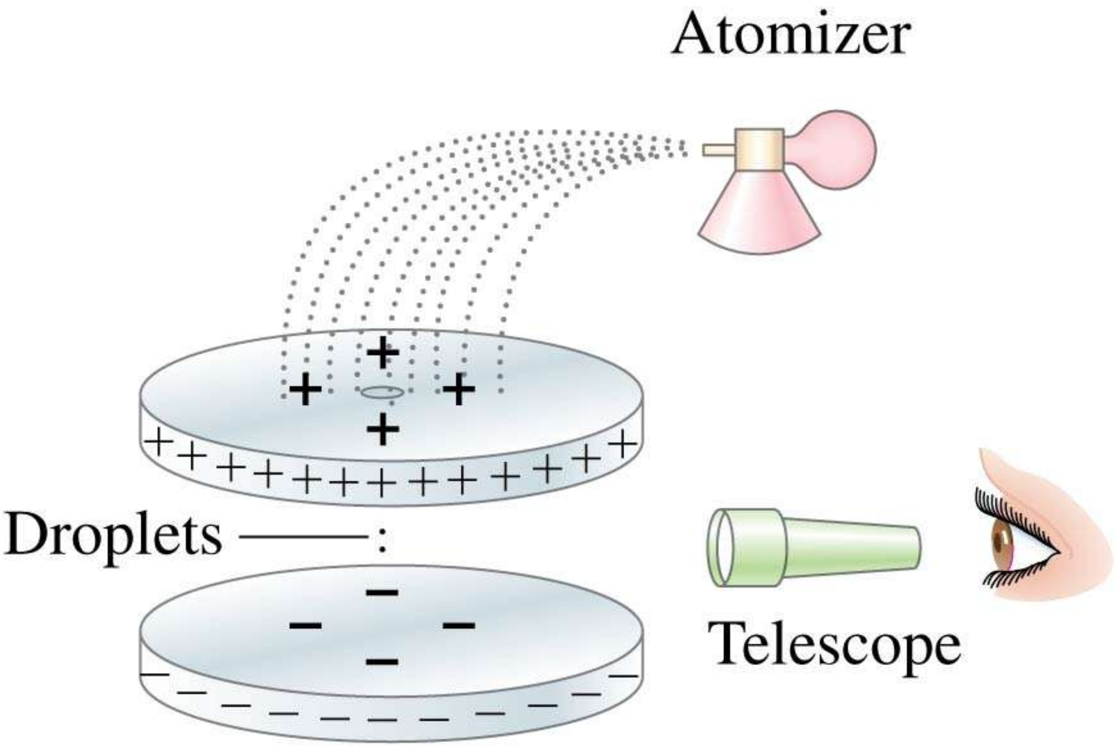
Ch. 27 Cathode Rays

- J. J. Thomson 1897. Discovered electrons. e/m



CH. 27 CATHODE RAYS

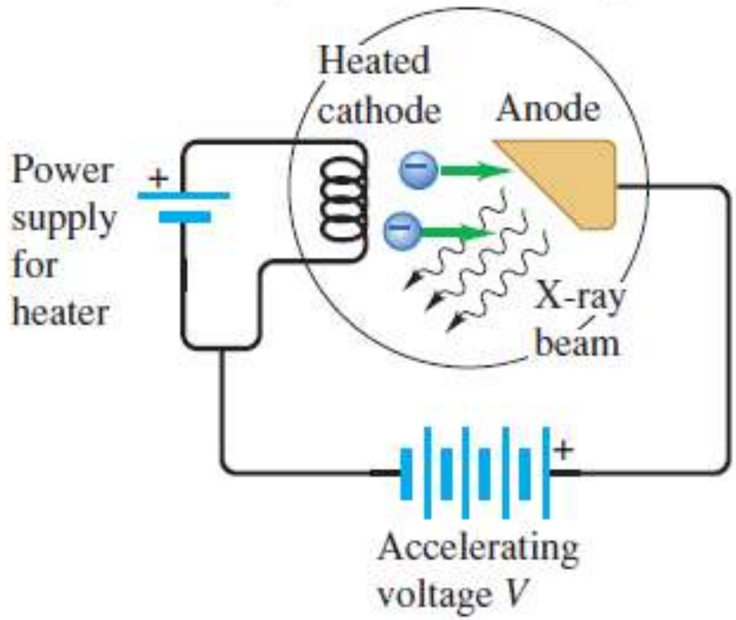
- 1900? Robert A. Millikan's oil-drop experiment.
- charge is quantized in e. Measured e. Now we know m.



Vacuum Tubes. X-rays, photocells,...

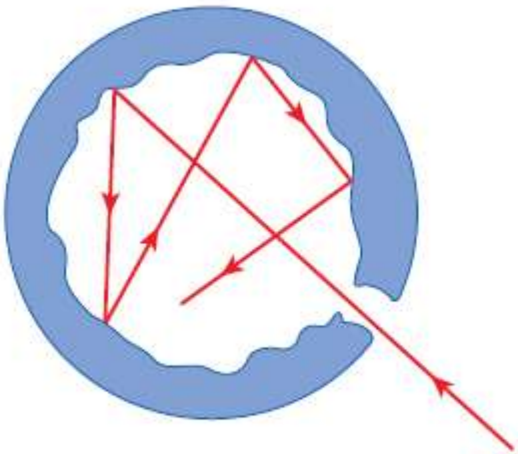
38.7 An apparatus used to produce x rays, similar to Röntgen's 1895 apparatus.

Electrons are emitted thermionically from the heated cathode and are accelerated toward the anode; when they strike it, x rays are produced.



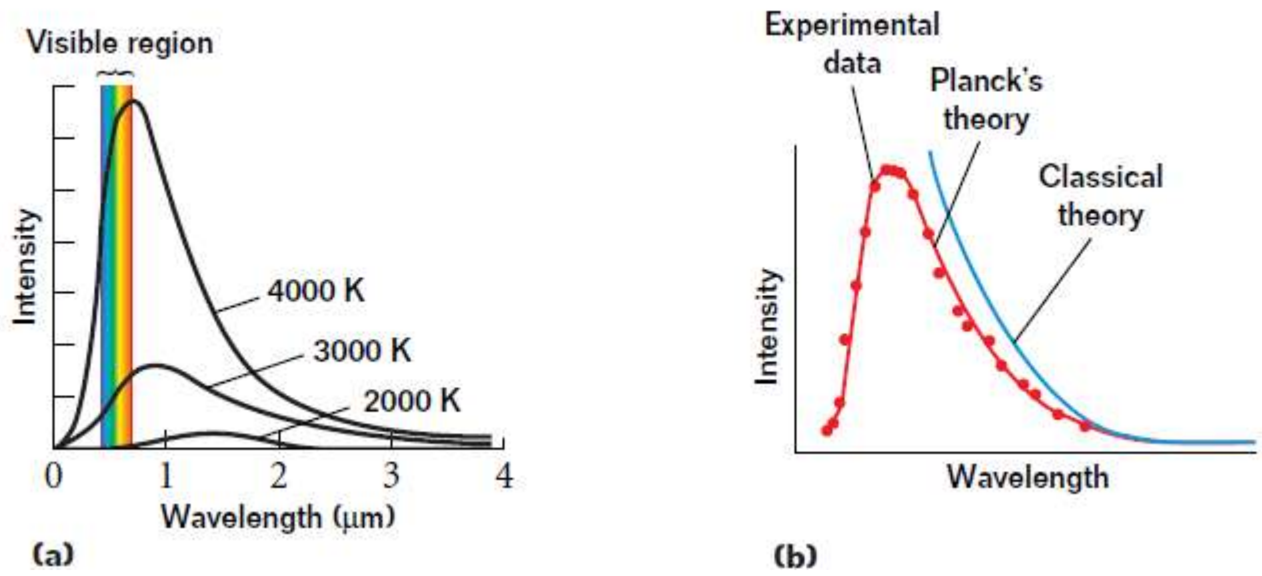
PLANCK BLACKBODY RADIATION– MORE DETAIL

- Black = good absorber, good emitter.
- Hollow absorbs most energy of incoming light with many reflections. Each bounce = absorb + give off. Many times means any light coming out the opening is in equilibrium with the light given off by the walls themselves (Holt)



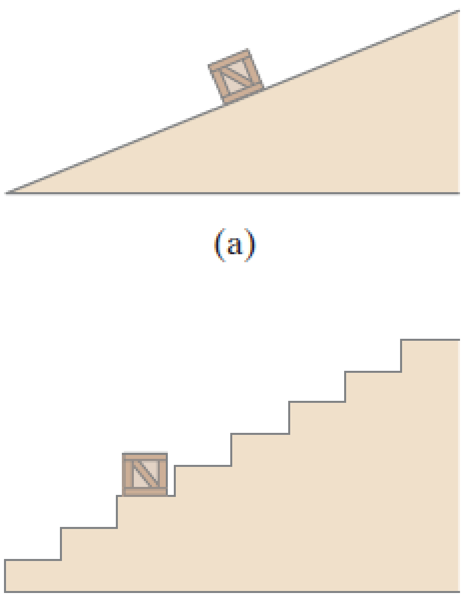
PLANCK BLACKBODY RADIATION

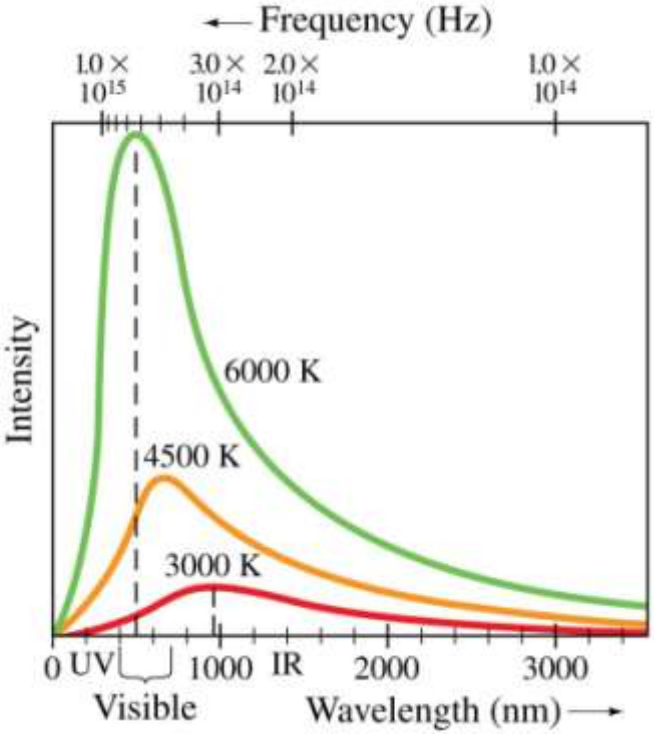
- Higher temperature, shake faster, more energy (area under the curve) given off. Notice the skew, nonsymmetric.
- Classically: As frequency increases, amount of radiated energy goes to infinity.
- This does not match experiment → Ultraviolet catastrophe!



PLANCK'S QUANTUM HYPOTHESIS: E = *hf*

- Planck's Quantum Hypothesis. Energy is quantized in multiples of hf. (Energy of oscillations of atoms in molecules is quantized and depends on frequency of oscillation) hf
- Mathematical device to get the right answer using statistics to fit the blackbody radiation curves.



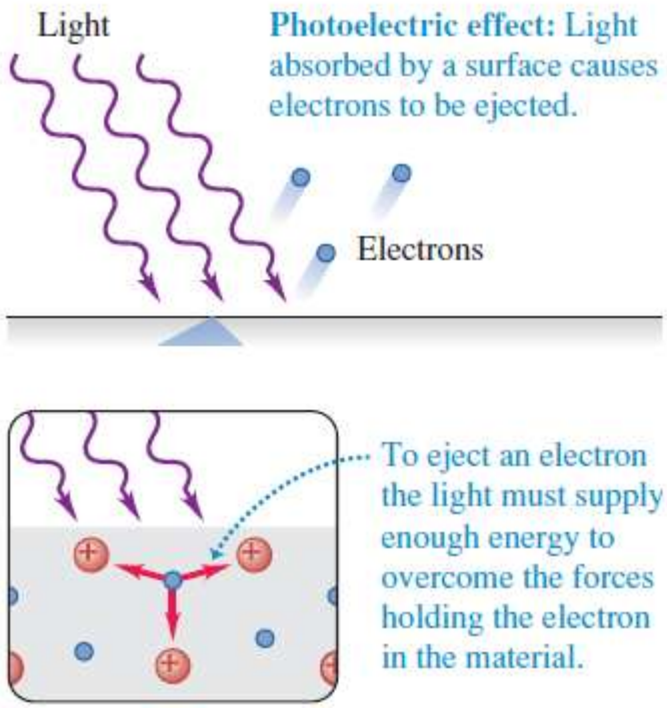


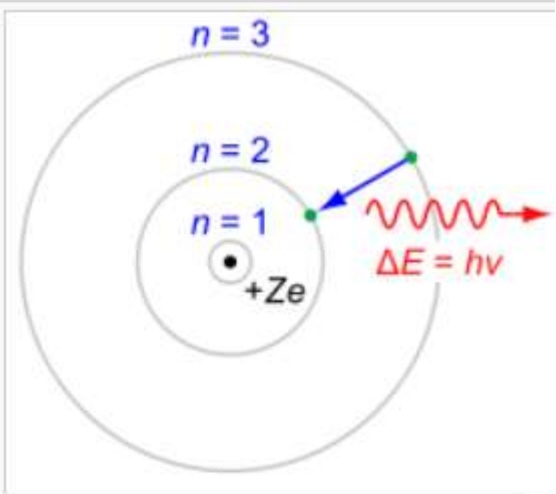
PHOTOELECTRIC EFFECT

- 1905 paper, same year as his introduction to special relativity.
- Einstein won the Nobel Prize for his paper explaining the photoelectric effect. Not just mathematical. Planck's hypothesis interpreted as photons (energy packets).
- Light as a wave and as a particle.

Ch. 27 Photoelectric Effect

38.1 The photoelectric effect.



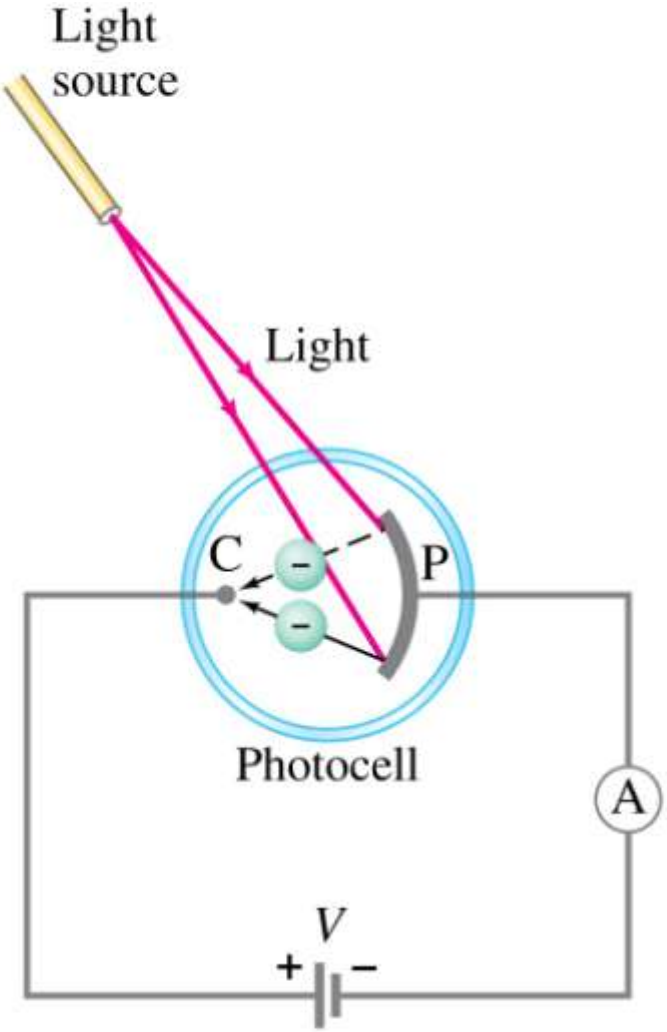


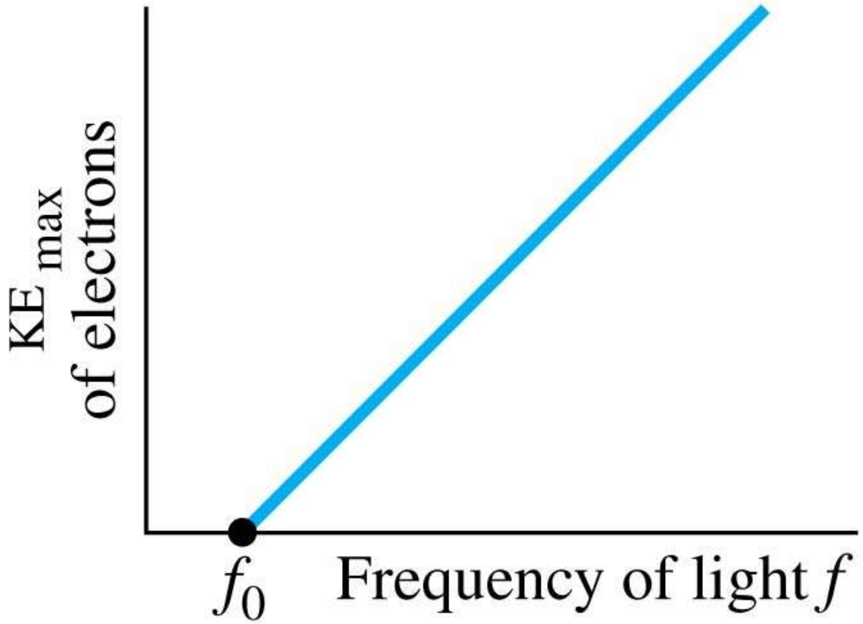
The Rutherford–Bohr model of the hydrogen atom.

Table 1 The Photoelectric Effect

	Classical predictions	Experimental evidence
Whether electrons are ejected depends on . . .	the intensity of the light.	the frequency of the light.
The kinetic energy of ejected electrons depends on . . .	the intensity of the light.	the frequency of the light.
At low intensities, electron ejection . . .	takes time.	occurs almost instantaneously above a certain frequency.

Photoelectric Effect

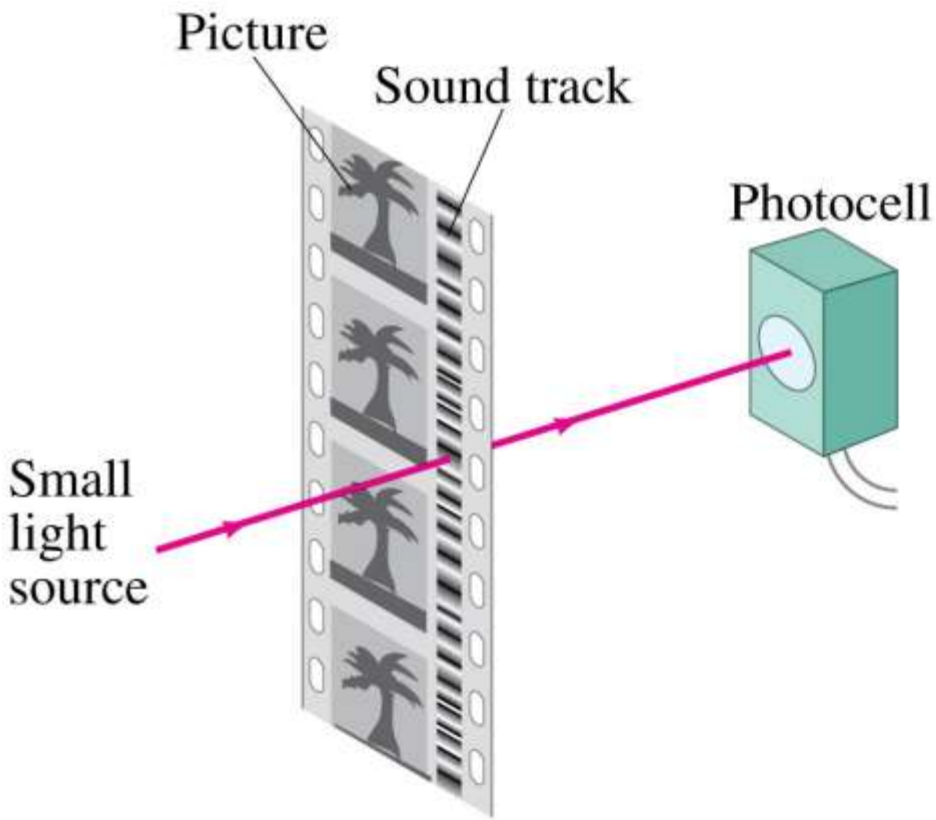




-   +

Should be

Photoelectric Effect



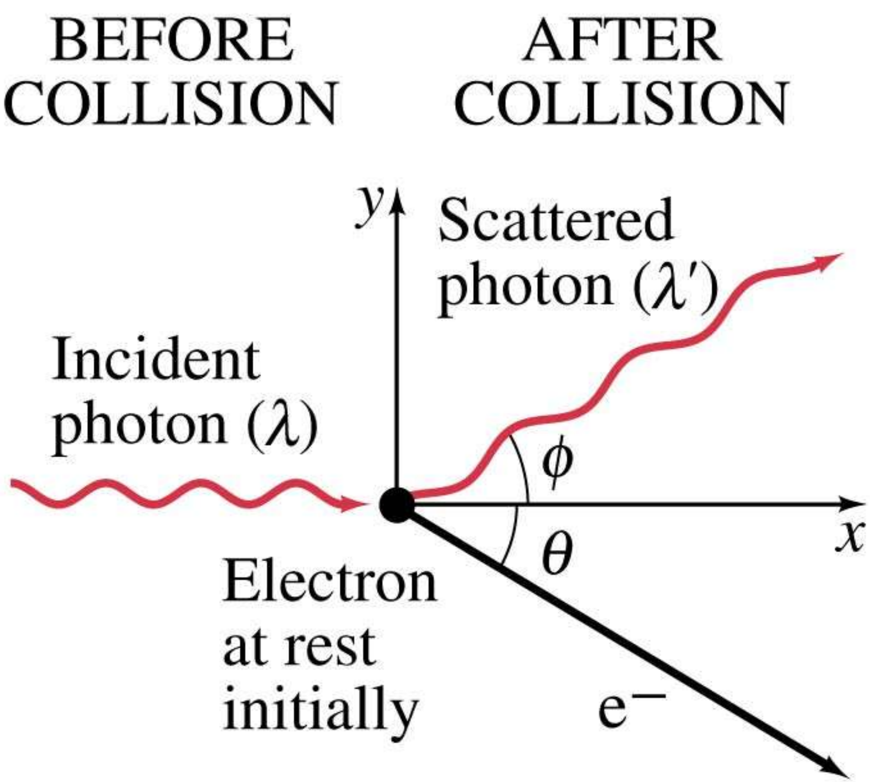
27-5 Compton Effect

This is another effect that is correctly predicted by the photon model and not by the wave model.

Wave:

electron oscillates at incoming f. Reemits at that f

no change with angle.



Really:

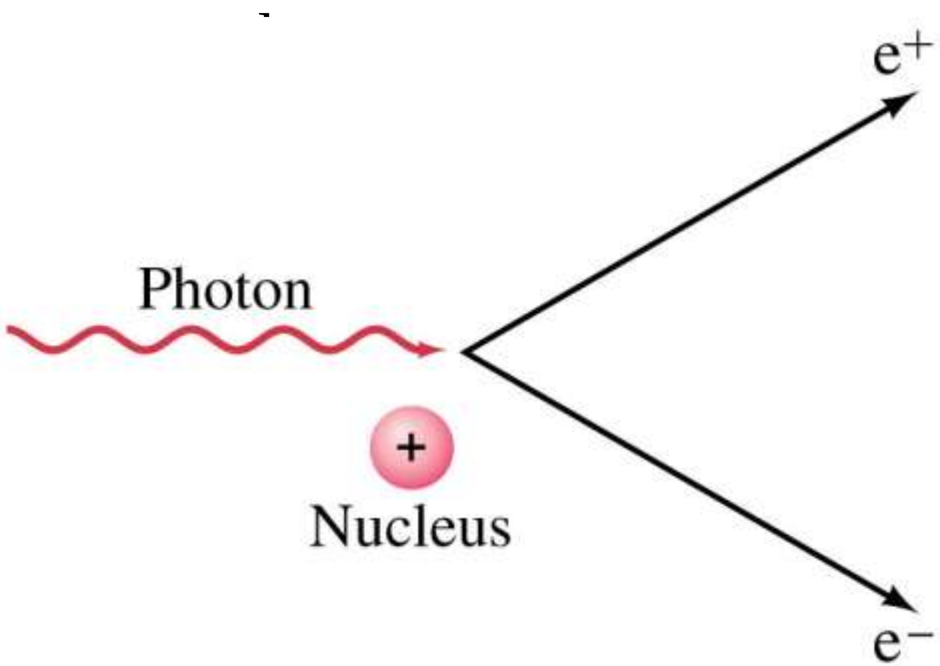
Reemits at lower f

varies with angle

(momentum conserved)

27-6 Photon Interactions; Pair Production

In pair production, energy, electric charge, and momentum must all be conserved.

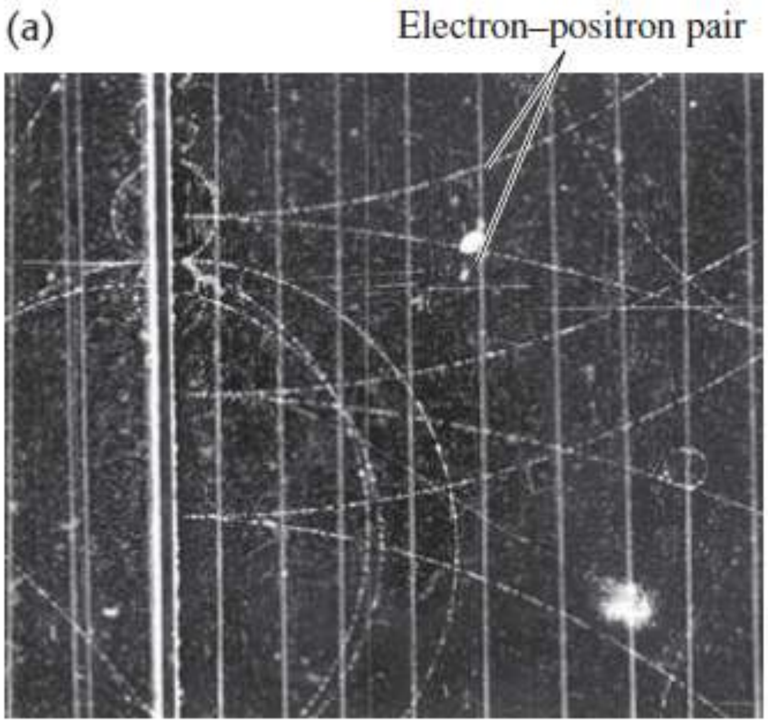


Energy will be through the mass and kinetic energy of the electron and positron; their opposite charges conserve charge; and interaction must take place in the electro-magnetic field of a nucleus, which can contribute momentum.

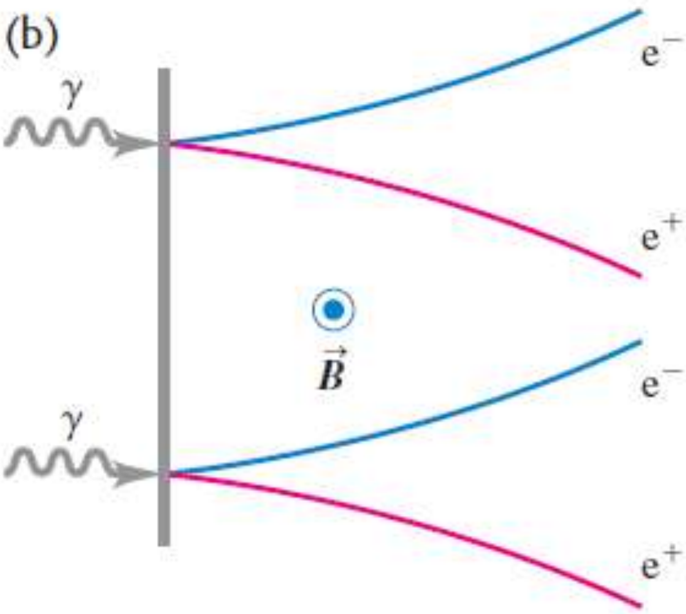
Pair Production in Bubble Chamber

38.14 (a) Photograph of bubble-chamber tracks of electron–positron pairs that are produced when 300-MeV photons strike a lead sheet. A magnetic field directed out of the photograph made the electrons (e^-) and positrons (e^+) curve in opposite directions. (b) Diagram showing the pair-production process for two of the gamma-ray photons (γ).

(a)



(b)



Conservation of Momentum?

- Light has momentum?

p = mv? But no mass?

(There's relativistic mass)

DEBROGLIE "DEBROY" WAVELENGTH

$$\lambda = \frac{h}{p}, \qquad (27\text{-}8)$$

- Light is a wave, can act as a particle.
- Can particles act as waves? → Matter Waves (Schrodinger)

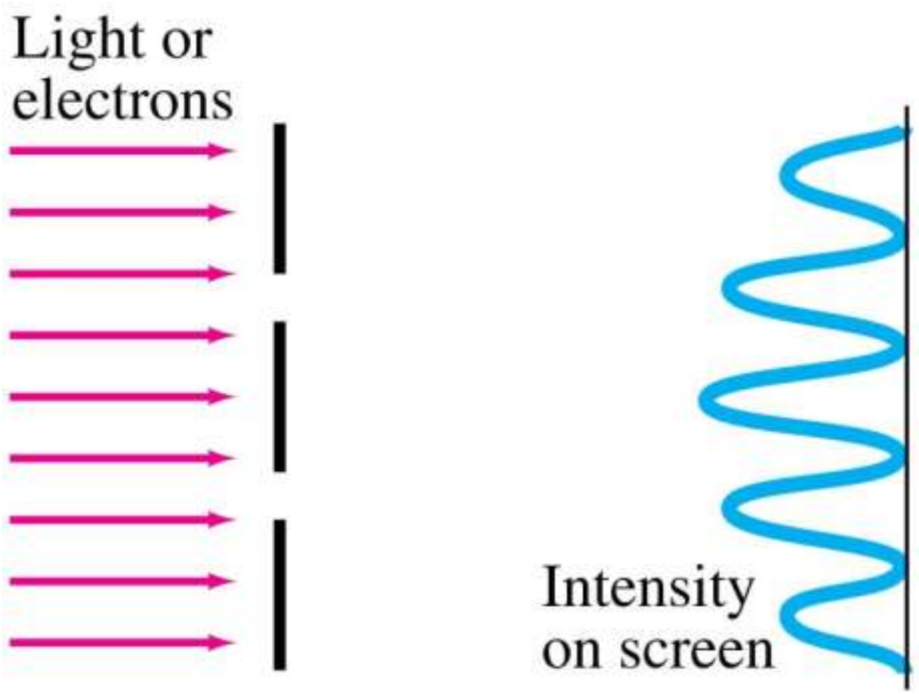
- Ex 10: Ball
- Ex11: Electron

- Big object, small speed → λ tiny
- Wave interference effects (diffraction fringes) are only apparent for ***<u>aperture <~ λ</u>***

28-2 The Wave Function and Its Interpretation; the Double-Slit Experiment

For example: the interference pattern is observed after many electrons have gone through the slits.

1 electron can go through both slits at the same time. (Wave)



If we send the electrons through one at a time, we cannot predict the path any single electron will take, but we can predict the overall distribution.

CH. 27 MATTER WAVES?

- N~brightness = intensity

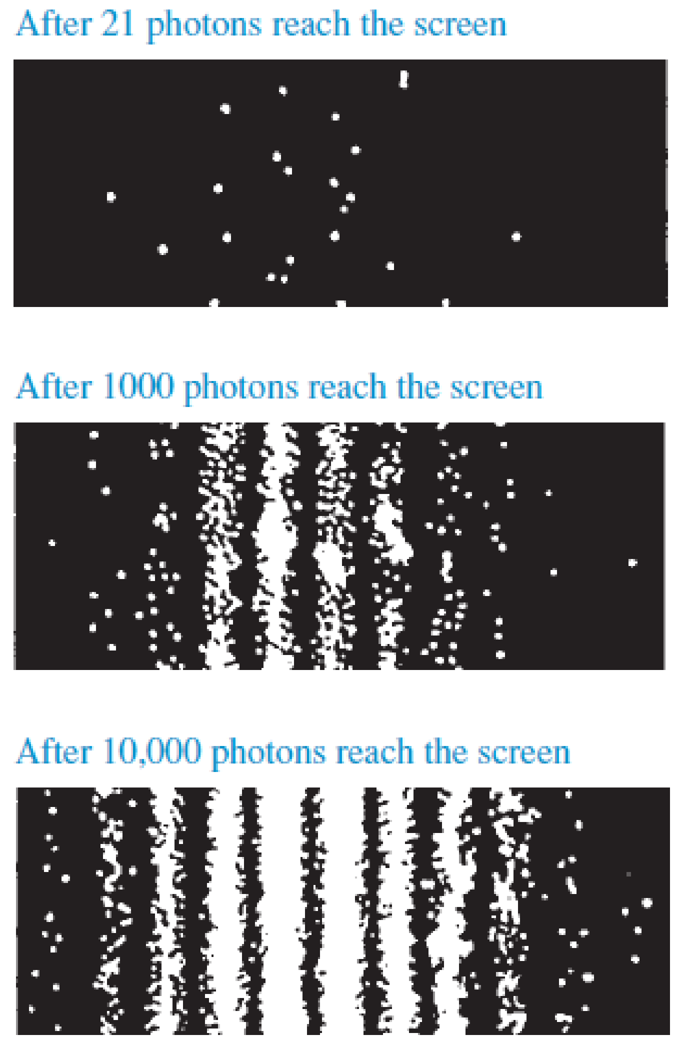
~ E^2

Likelihood (pdf) that a particle

is at location x at time t

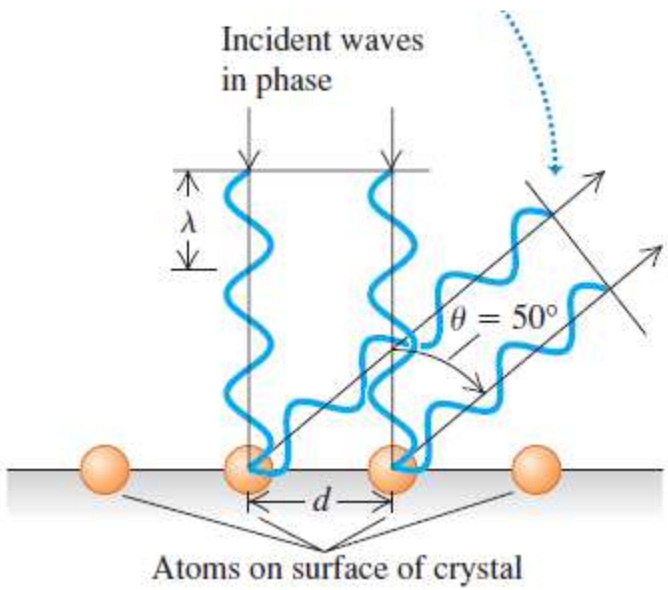
is given by

38.16 These images record the positions where individual photons in a two-slit interference experiment strike the screen. As more photons reach the screen, a recognizable interference pattern appears.



DEBROGLIE

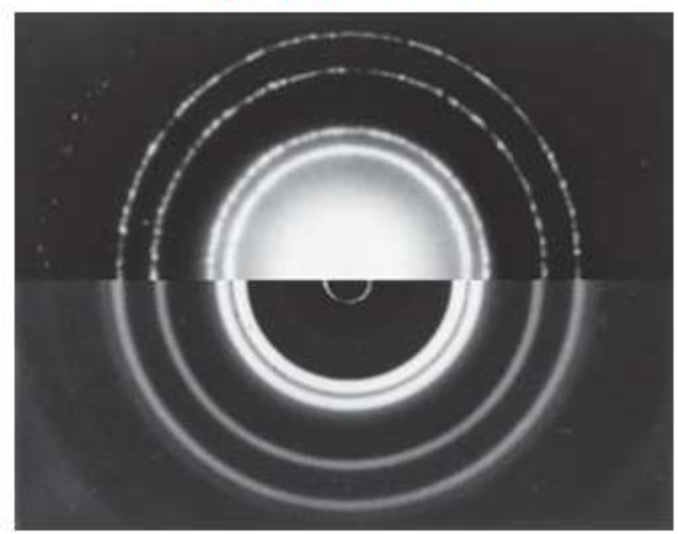
- Evidence: electrons diffract just like x-ray scattering.
- 1927 Davisson-Germer experiment. Atoms in crystal as diffraction grating.
- Ex 27.12



- Later: Protons, neutrons, others.
- 27.E, 27.F

39.4 X-ray and electron diffraction. The upper half of the photo shows the diffraction pattern for 71-pm x rays passing through aluminum foil. The lower half, with a different scale, shows the diffraction pattern for 600-eV electrons from aluminum. The similarity shows that electrons undergo the same kind of diffraction as x rays.

Top: x-ray diffraction



Bottom: electron diffraction

ERWIN SCHRÖDINGER 1926

$$-\frac{\hbar^2}{2m}\frac{\partial^2\Psi(x,t)}{\partial x^2} = i\hbar\frac{\partial\Psi(x,t)}{\partial t}$$ (one-dimensional Schrödinger equation for a free particle)

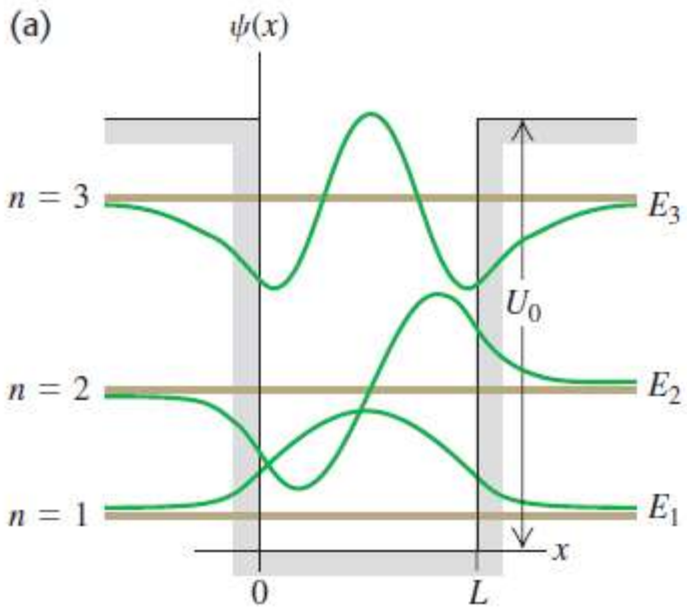
$$\Psi(x,t) = A[\cos(kx-\omega t) + i\sin(kx-\omega t)]$$ (sinusoidal wave function representing a free particle)

$$e^{i\theta} = \cos\theta + i\sin\theta$$

$$\Psi(x,t) = Ae^{i(kx-\omega t)} = Ae^{ikx}e^{-i\omega t}$$ (sinusoidal wave function representing a free particle)

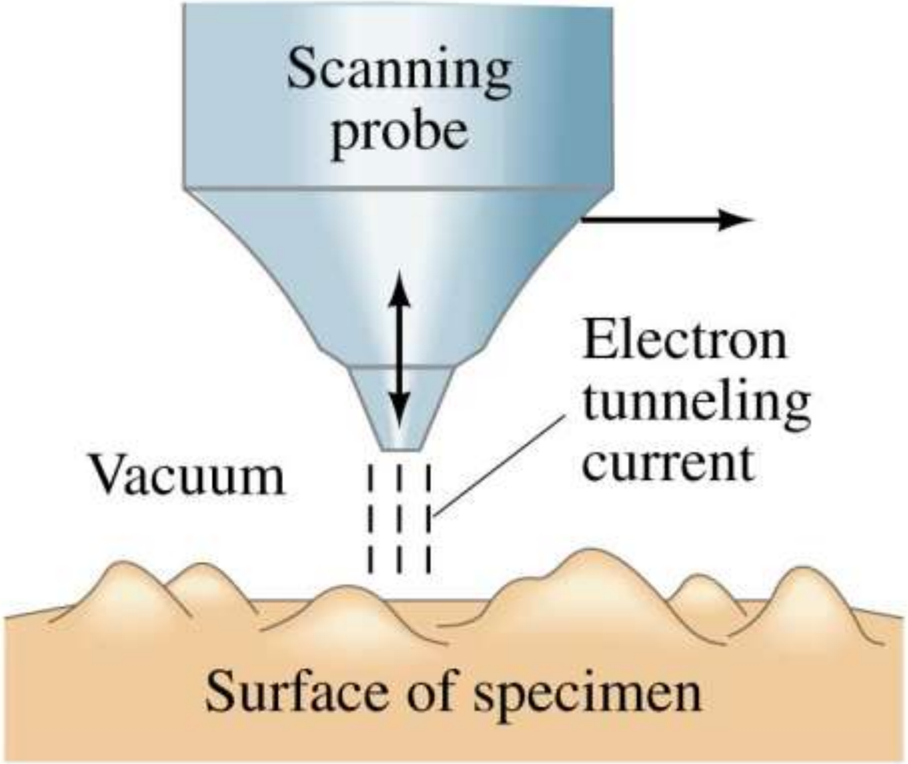
$$\boxed{|\Psi(x,t)|^2} = \Psi^*(x,t)\Psi(x,t) = (A^*e^{-ikx}e^{i\omega t})(Ae^{ikx}e^{-i\omega t})$$
$$= A^*Ae^0 = |A|^2$$

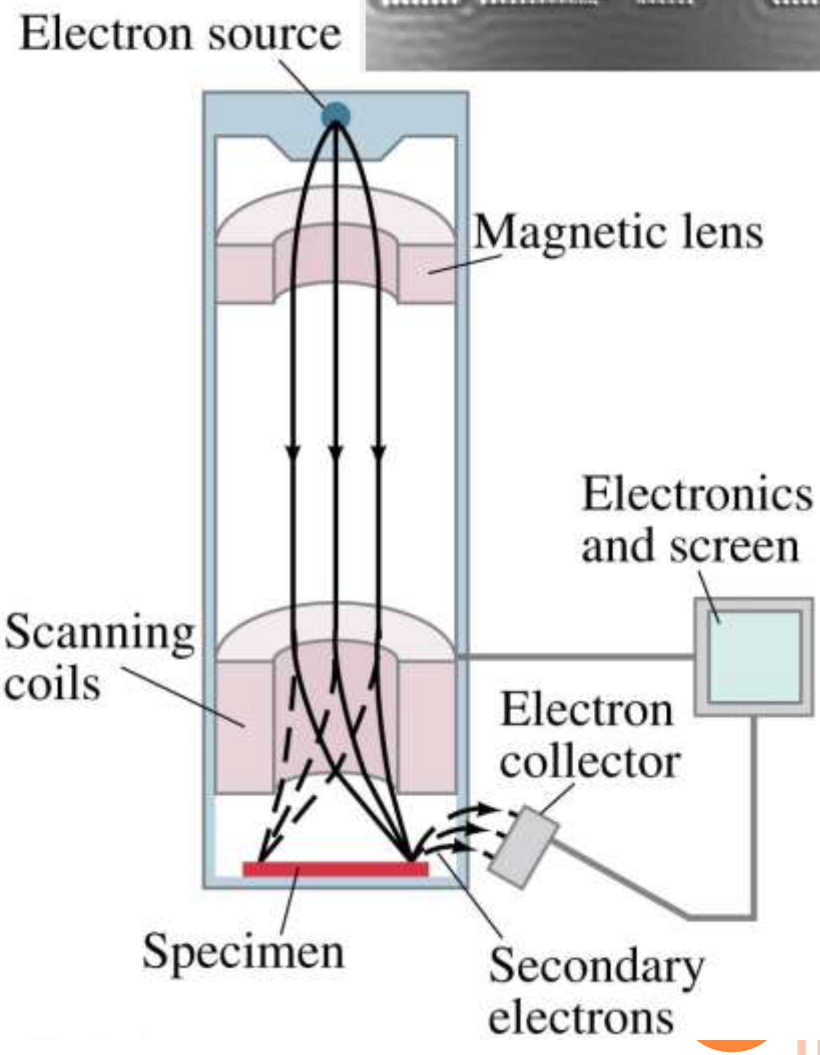
QUANTUM TUNNELING



ELECTRONS BEHAVE LIKE WAVES

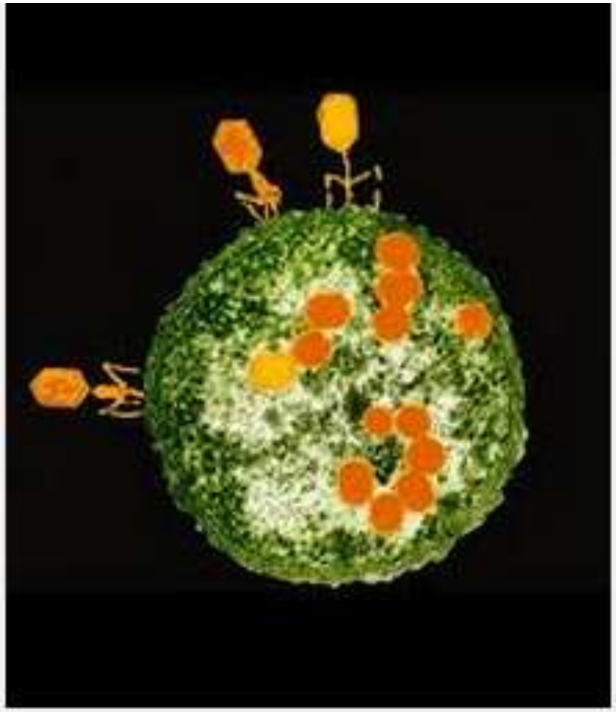
- Quantum tunneling.
- Magnetic lens, instead of optical



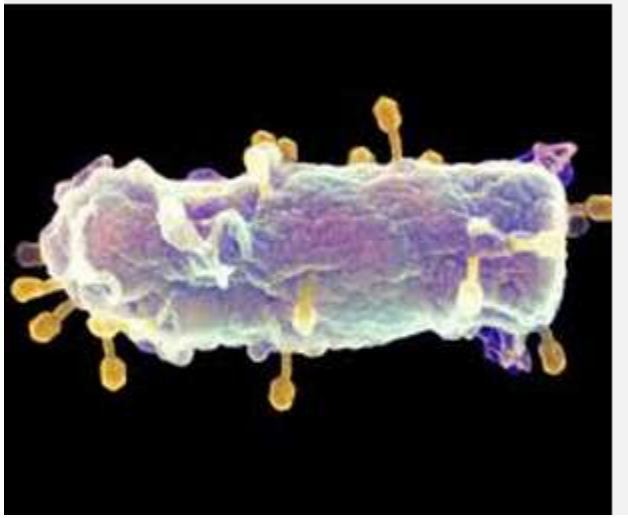


ELECTRON MICROGRAPHS

- viruses attacking E.coli bacterium

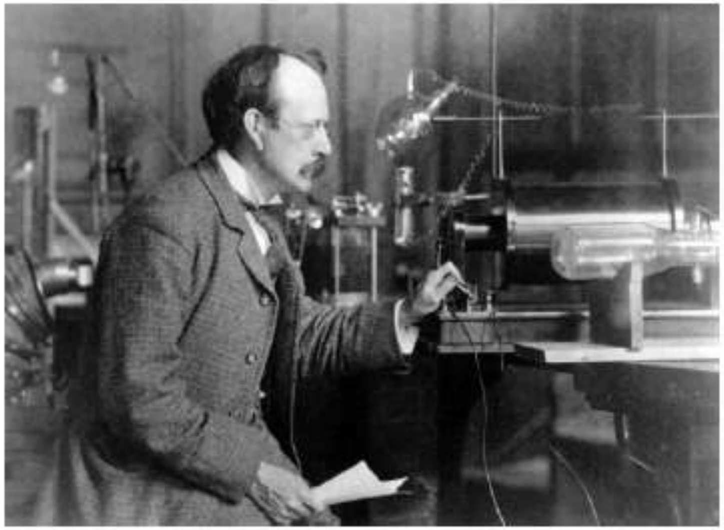


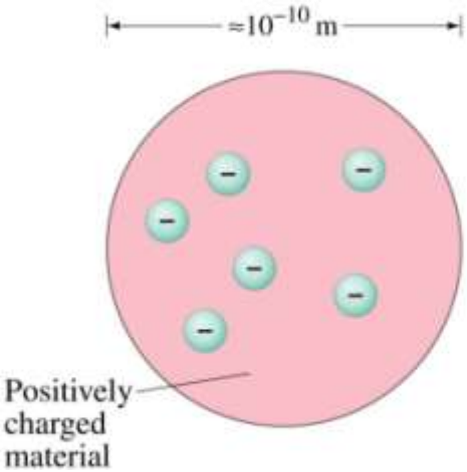
- similar image by SEM



Discovery of the Electron

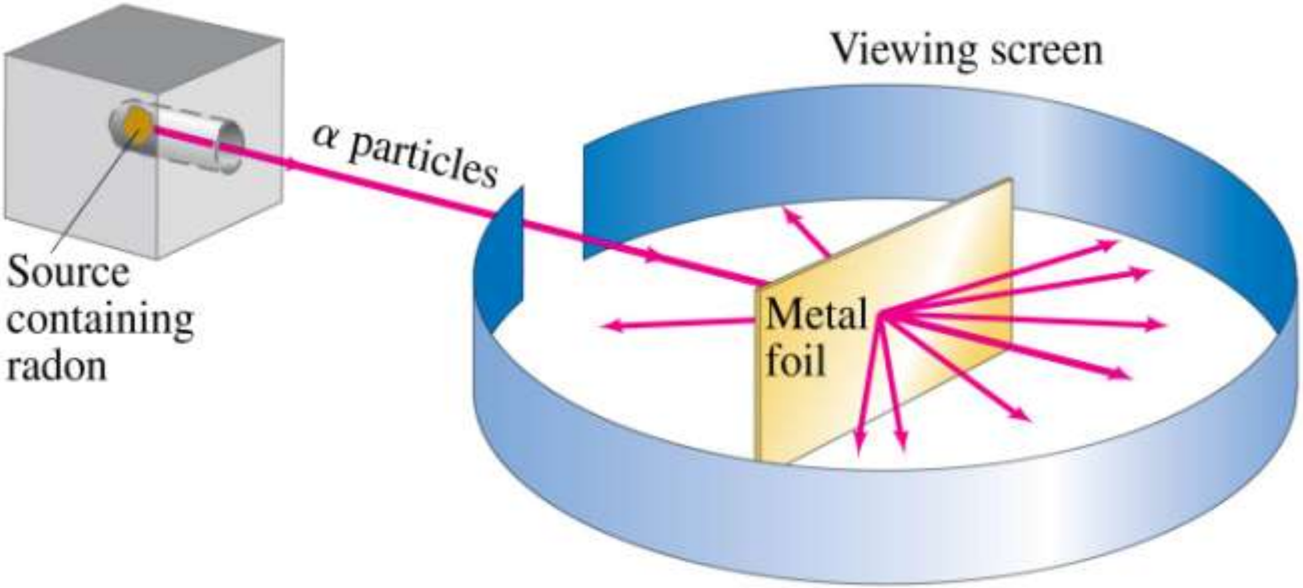
- J. J. Thomson
  - Nobel Prize: Thomson, Son and Students





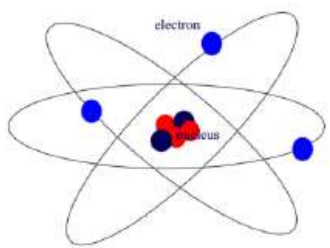
Discovery of the Nucleus

- 1911 Ernest Rutherford.
- There's something in the plum pudding.
- Mostly empty space (stadium, pin)



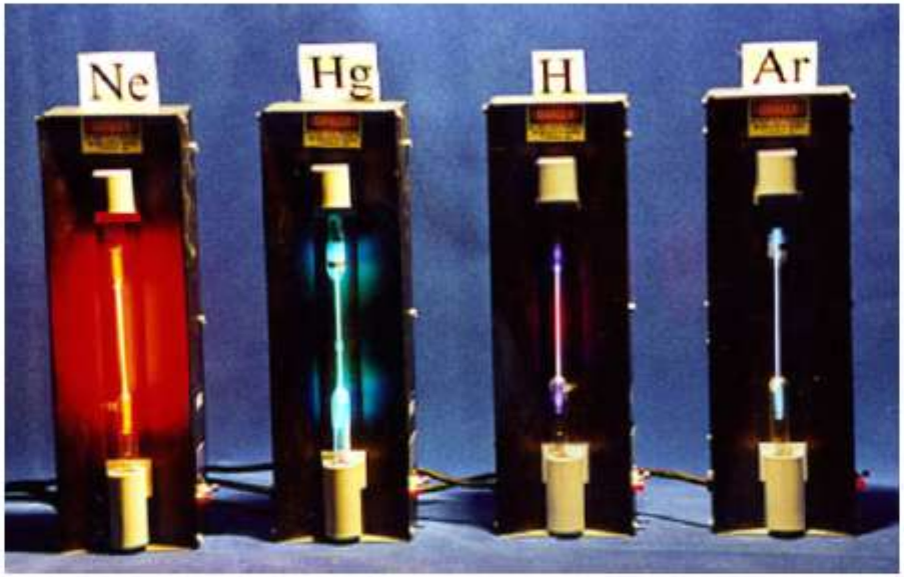
"It was quite the most incredible event that has ever happened to me in my life. It was almost as if you fired a fifteen-inch shell into a piece of tissue paper and it came back and hit you."

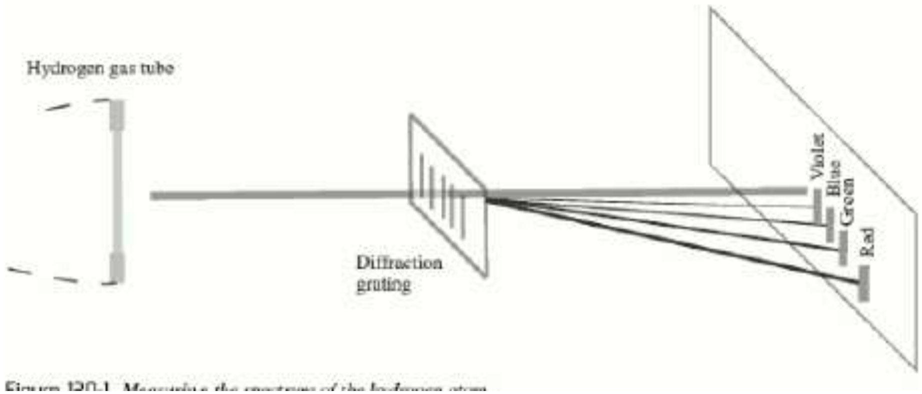
Rutherford Model



Atomic Planetary Model

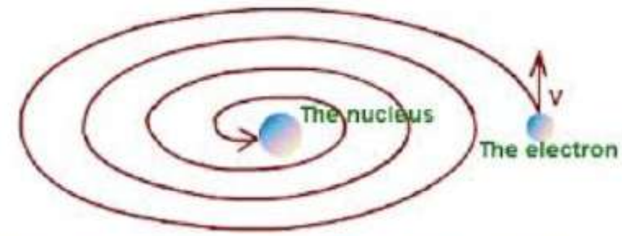
Emission Spectrum: energy levels are quantized



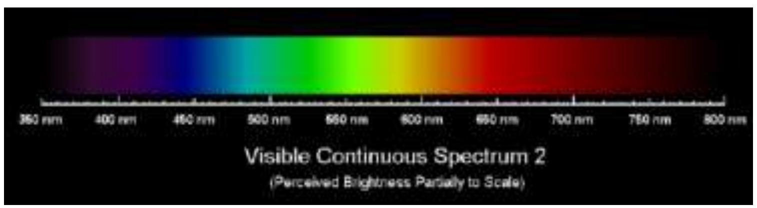


RUTHERFORD CONTRADICTION

- Electrons moving in orbit must give off light like an antenna.
- Lose energy
- Spiral into the nucleus.
- Give off light in a continuum of colors.
- Contradicts Spectra



In the planetary model of atom, the electron should emit energy and spirally fall on the nucleus.

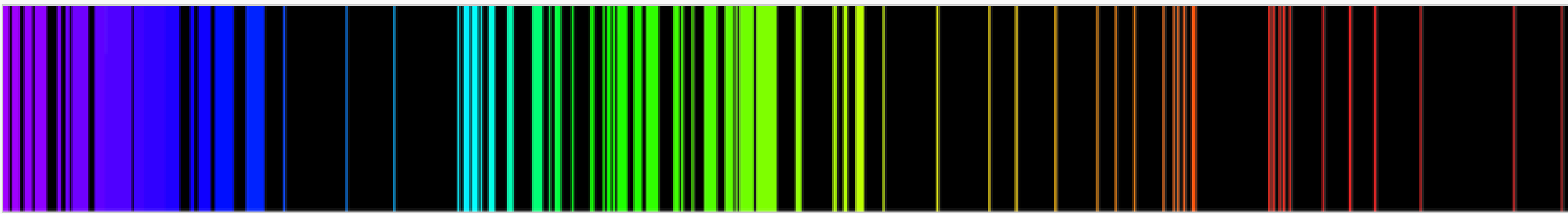


Atomic Spectra

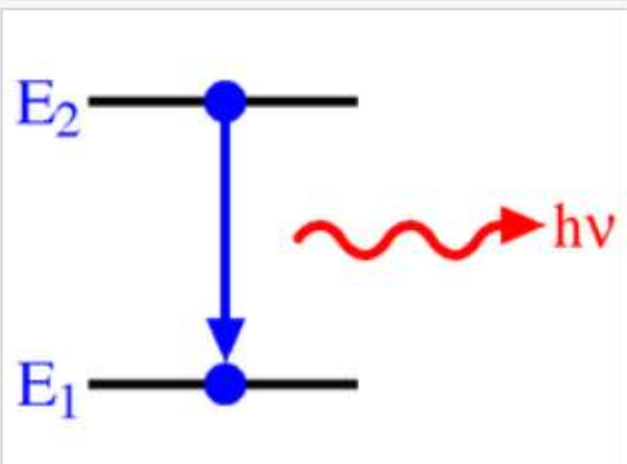
- Rutherford Model - Atom is mostly empty space with all the positive charge concentrated in a tiny massive central core. He also suggested a planetary model where electrons orbit the nucleus. Although a major step forward, this model was flawed.
- Heated solids, liquids and dense gases emit light with a continuous spectrum of wavelengths. Less dense gases emit a discrete spectrum (emitted ligh is due to individual atoms, not interactions between atoms).

EMISSION SPECTRUM: ENERGY LEVELS ARE QUANTIZED

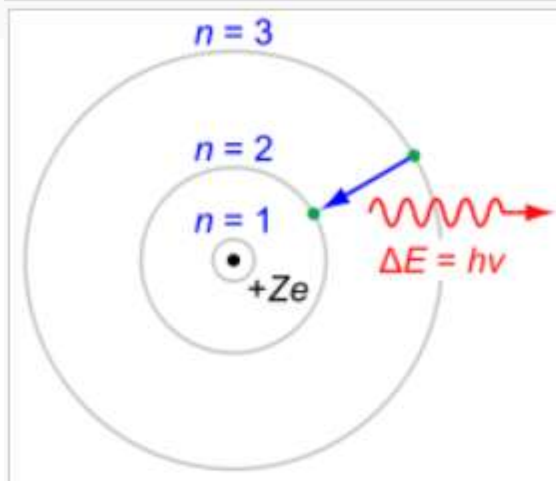
Emission spectrum of Hydrogen



Emission sp



Schematic diagram of spontaneous emission

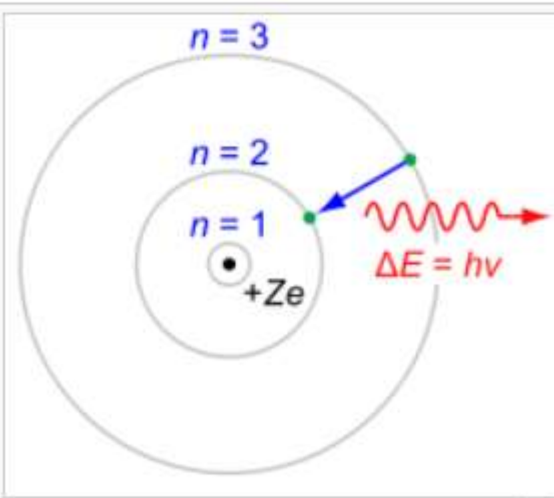


The Rutherford–Bohr model of the hydrogen atom.

- Wikipedia
- Emission spectrum
- Atomic orbital

Bohr Model

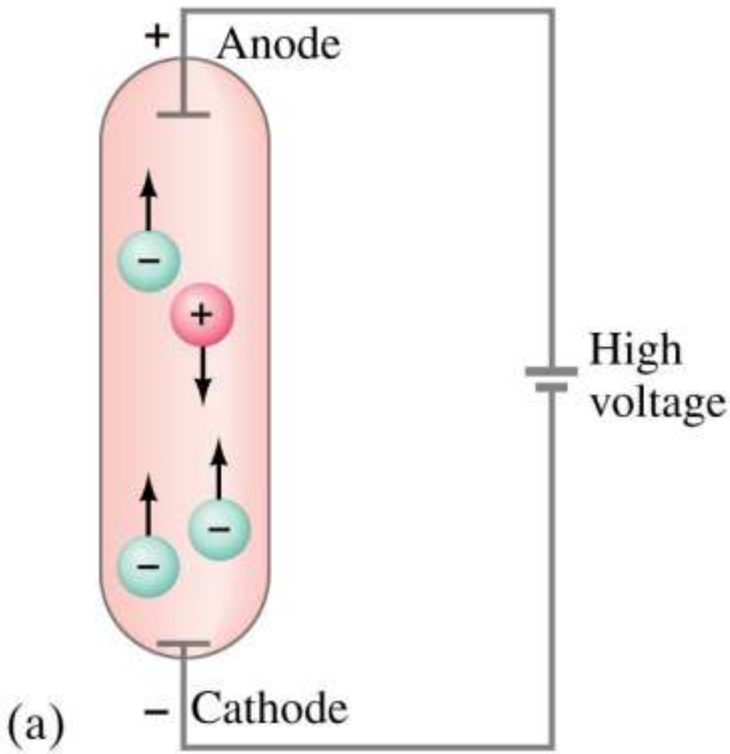
- derive the spectra line equations and Rydberg constant
- only works for simple atoms with 1 electron. For 2 or more, see Ch. 28~29.
- (most modern model is the electron cloud)
  - high likelihood corresponds to orbital in Bohr model.

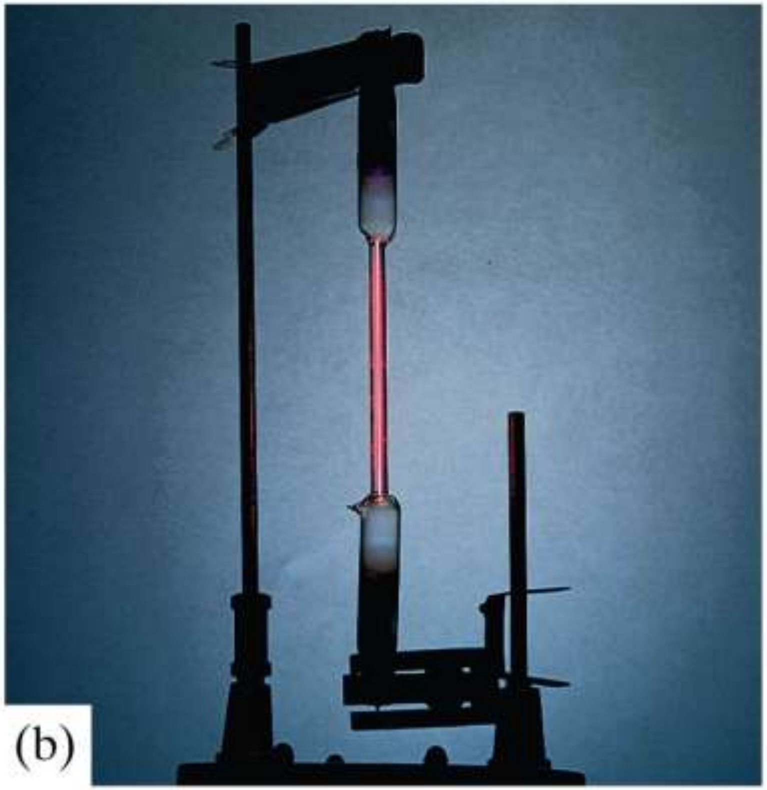


The Rutherford–Bohr model of the hydrogen atom.

27-11 Atomic Spectra: Key to the Structure of the Atom

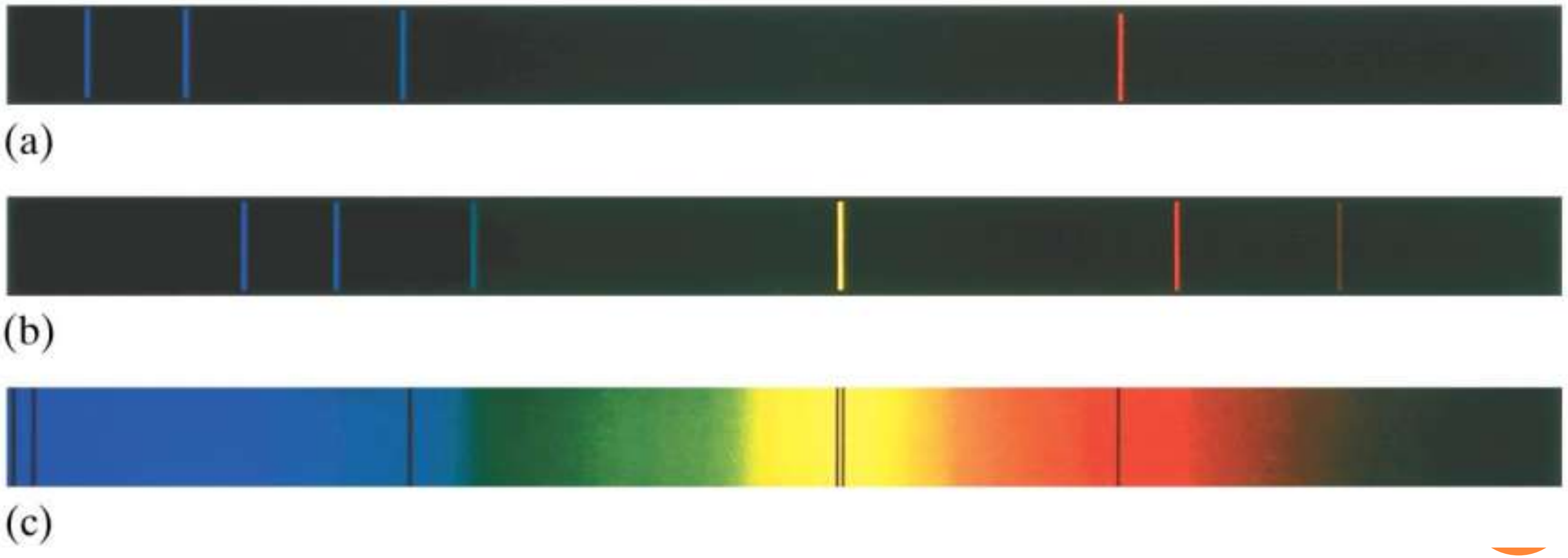
A very thin gas heated in a discharge tube emits light only at characteristic frequencies.





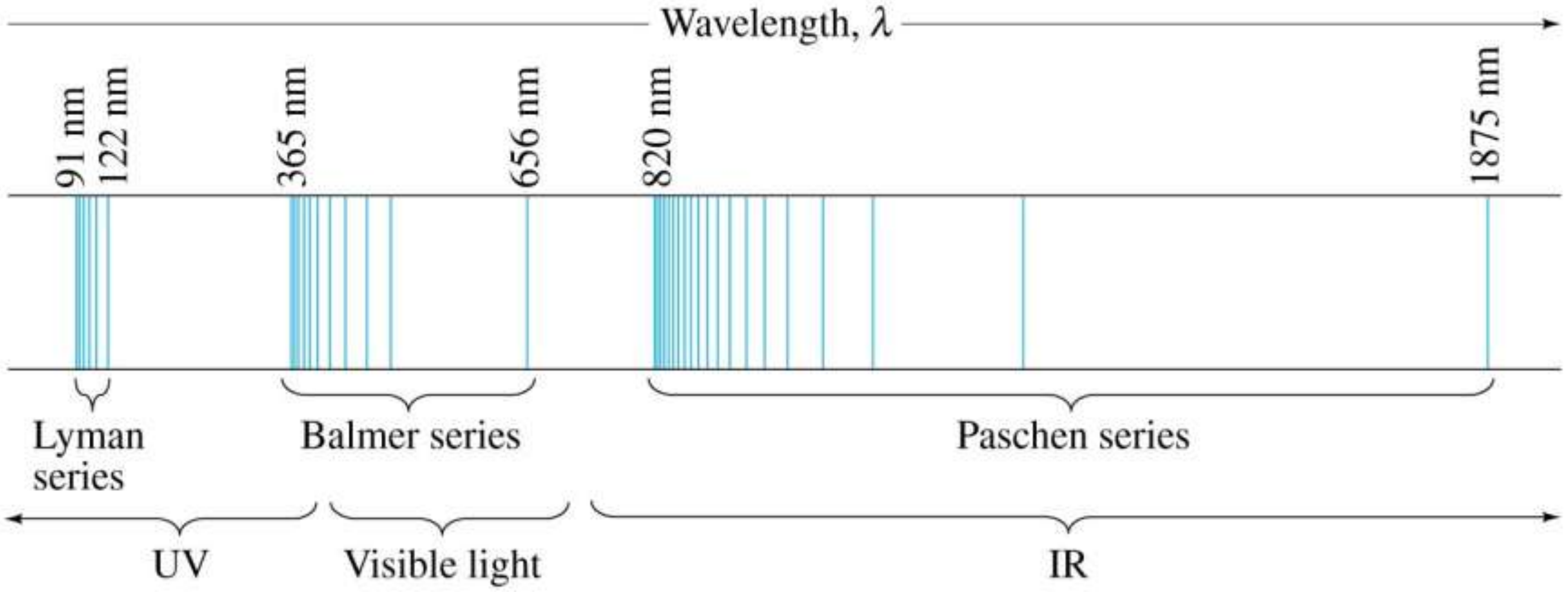
27-11 Atomic Spectra: Key to the Structure of the Atom

An atomic spectrum is a line spectrum—only certain frequencies appear. If white light passes through such a gas, it absorbs at those same frequencies.



27-11 Atomic Spectra: Key to the Structure of the Atom

A portion of the complete spectrum of hydrogen is shown here. The lines cannot be explained by the Rutherford theory.



27-11 Atomic Spectra: Key to the Structure of the Atom

The wavelengths of electrons emitted from hydrogen have a regular pattern:

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right), \qquad n = 3, 4, \cdots. \quad (27\text{-}9)$$

This is called the Balmer series. *R* is the Rydberg constant:

$$R = 1.0974 \times 10^7 \text{ m}^{-1}$$

27-11 Atomic Spectra: Key to the Structure of the Atom

Other series include the Lyman series:

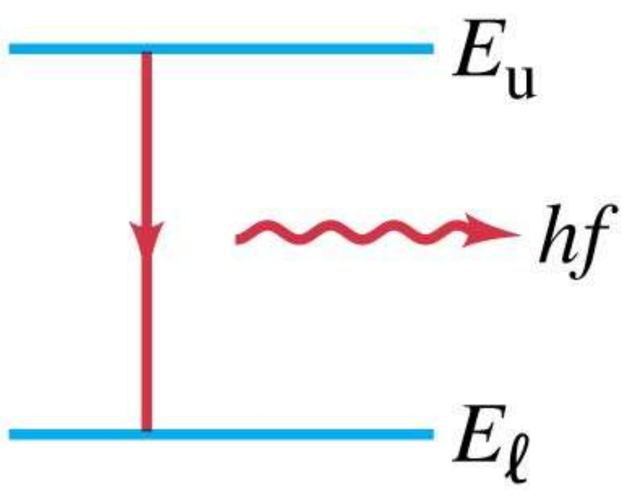
$$\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right), \qquad n = 2, 3, \cdots.$$

And the Paschen series:

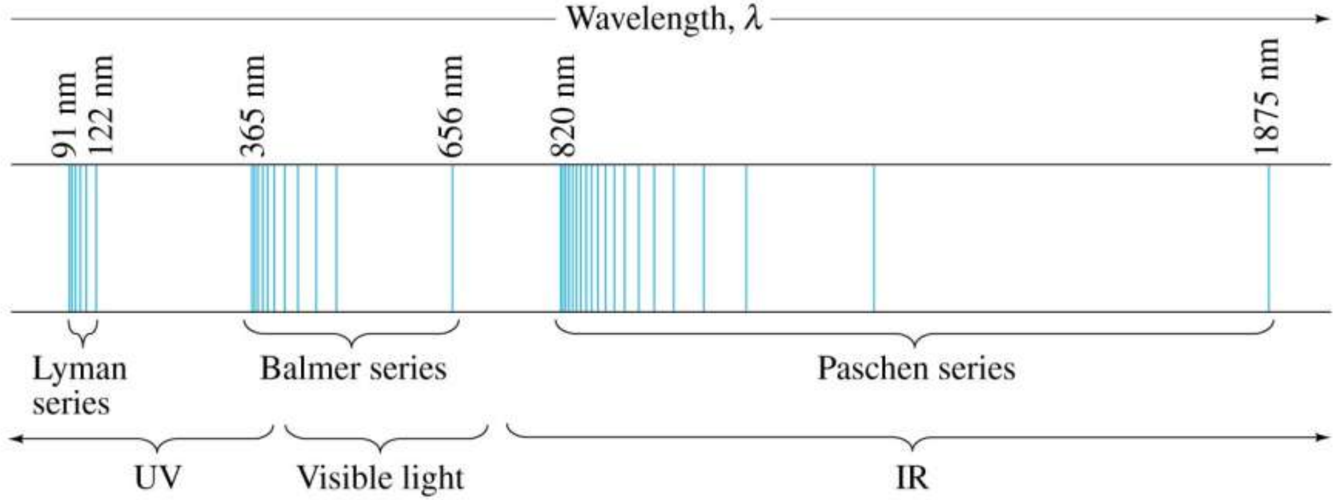
$$\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right), \qquad n = 4, 5, \cdots.$$

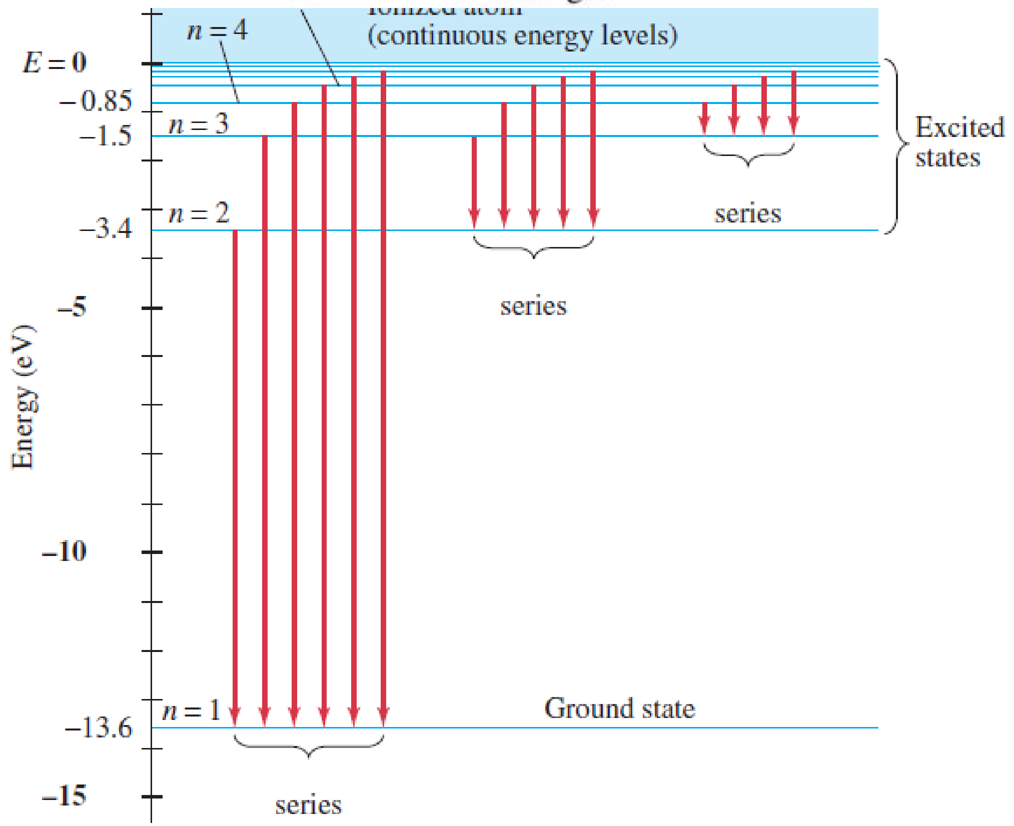
27-12 The Bohr Atom

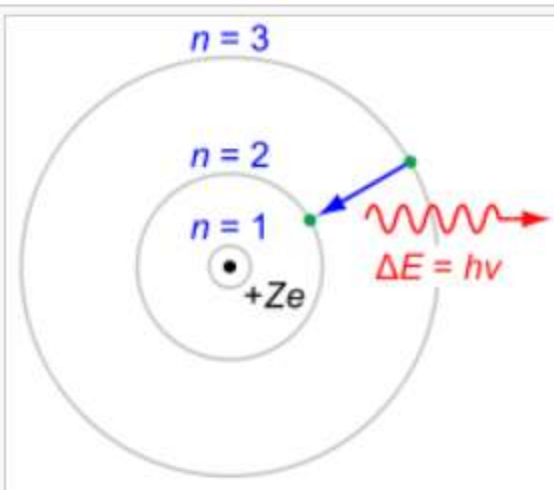
Bohr proposed that the possible energy states for atomic electrons were quantized—only certain values were possible. Then the spectrum could be explained as transitions from one level to another.



GUESS WHICH: LYMANN. BALMER. PASCHEN SERIES?

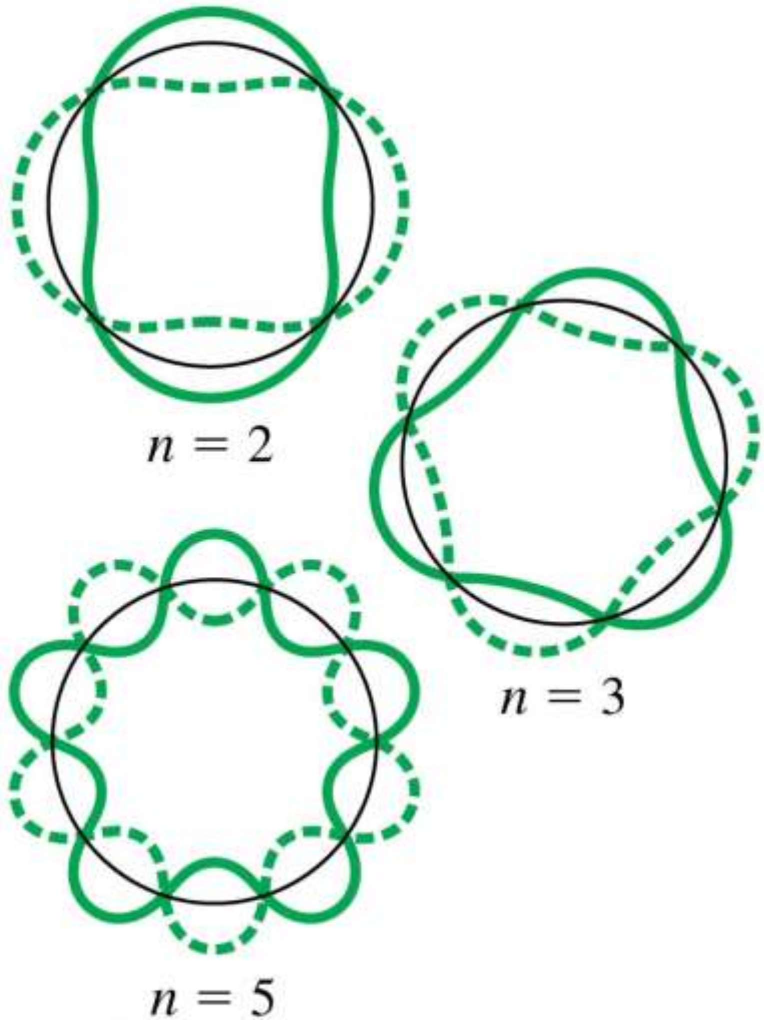






The Rutherford–Bohr model of the hydrogen atom.

deBroglie's Hypothesis



REVIEW

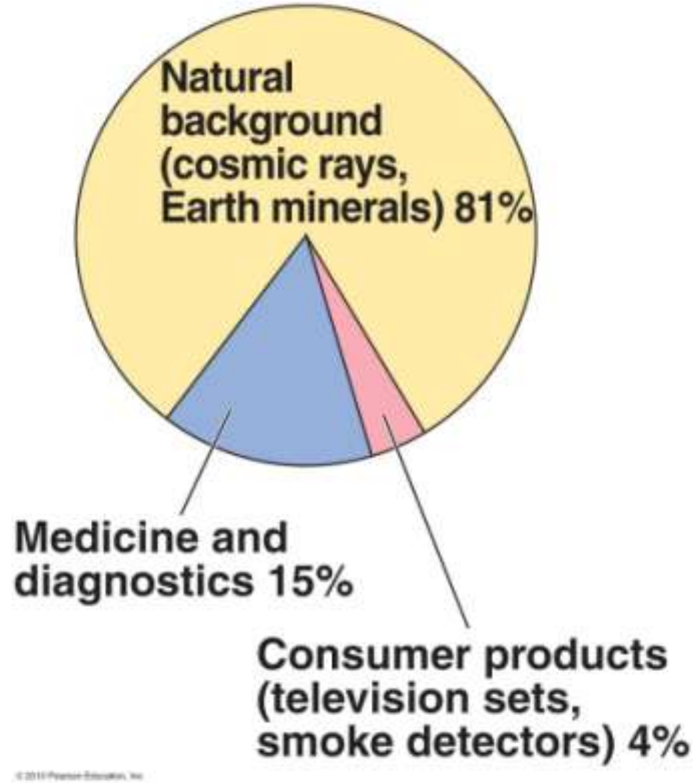
- What?
- Who?
- Evidence?

1. Quantization of Energy (why photons?)
2. Why hypothesize Discrete Orbitals?
3. Why discrete orbitals?
4. Wave-Particle duality?

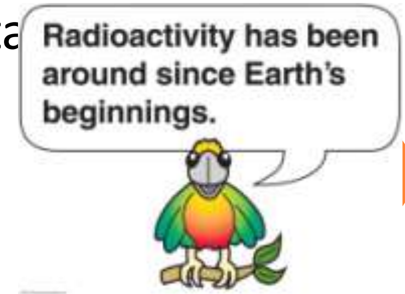
Ch. 30 Atomic energy

AP Physics B

RADIOACTIVITY



- "Radioactive" unstable nucleus.
  - Proton and neutron not balanced
  - Falls apart (decays)
- Radioactivity is not a new thing!
  - Natural hot springs, geysers
  - High-altitude
  - Round-trip flight from NYC to LA ~ x-ray dose
  - Radon-222 from uranium deposits: heavy gas from rocks in basement
  - Concrete, brick houses have more radioactive substa than wood



16.1 Radioactivity

- 1896 Henri Becquerel

the nuclei of some atoms. Marie Curie, a scientist working with Becquerel, named the process by which some nuclei give off nuclear radiation. She named the process **radioactivity,** which is also called *radioactive decay*.

Figure 1 *Sunlight could not pass through the paper. So, the image on the plate must have been made by energy given off by the mineral.*

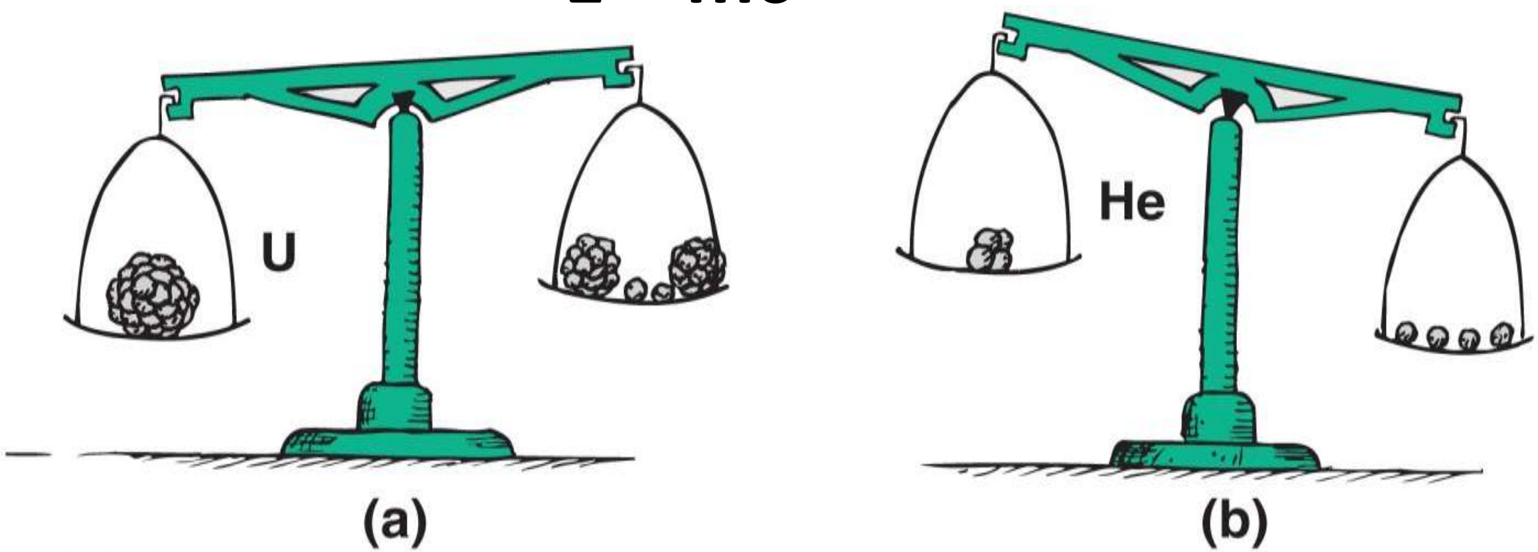
16.1 Radioactivity

- Named by ____________________
- What is radioactive decay?
- Does the element stay the same after radioactive decay?
- All isotopes with 83 protons or more (Bismuth) are radioactive.

16.1 RADIOACTIVITY

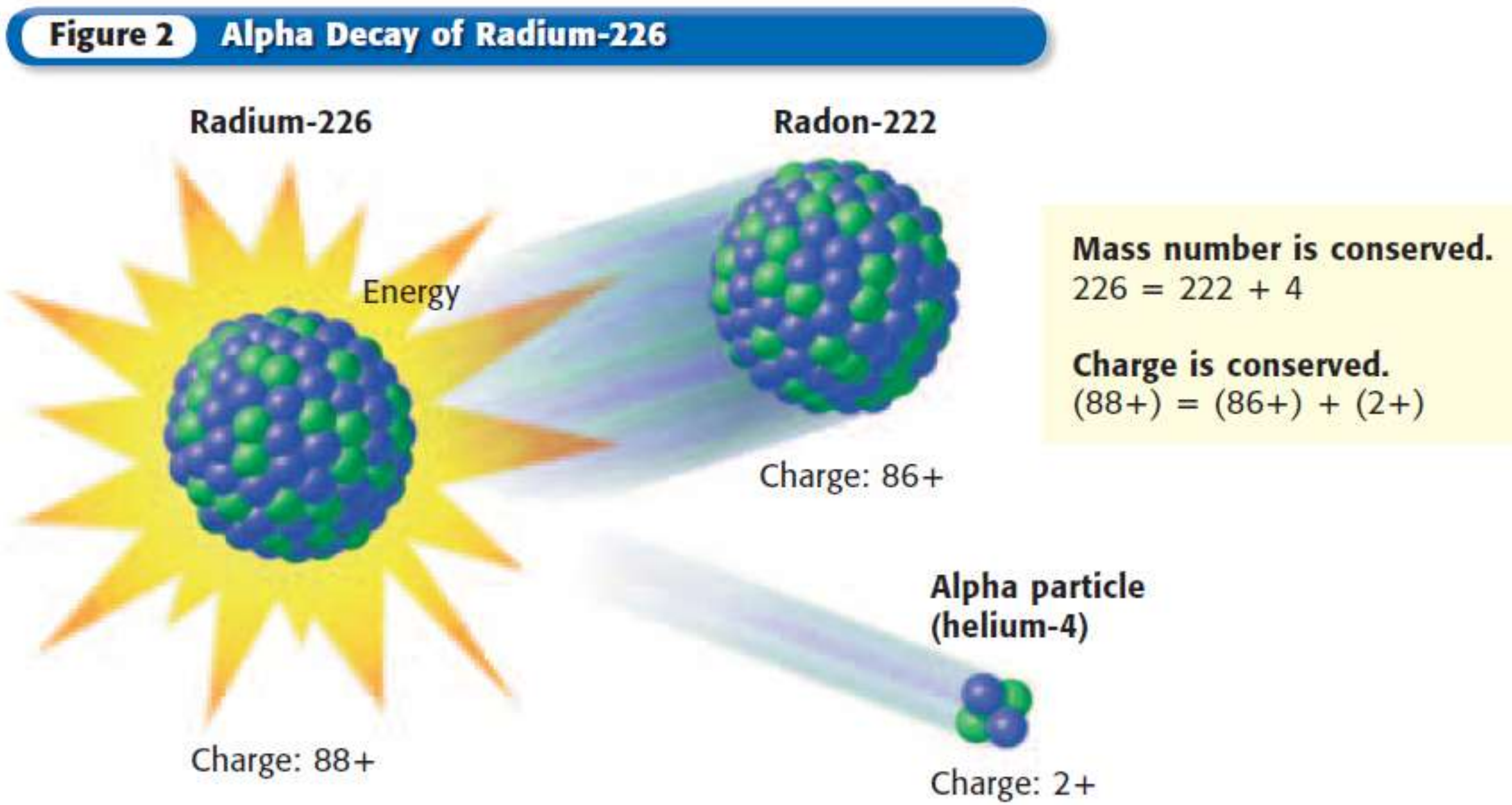
- Conservation in decay
  - Mass number stays the same
  - Electric charge stays the same
- Does <u>mass</u> stay the same?

$$E = mc^2$$



16.1 Radioactivity

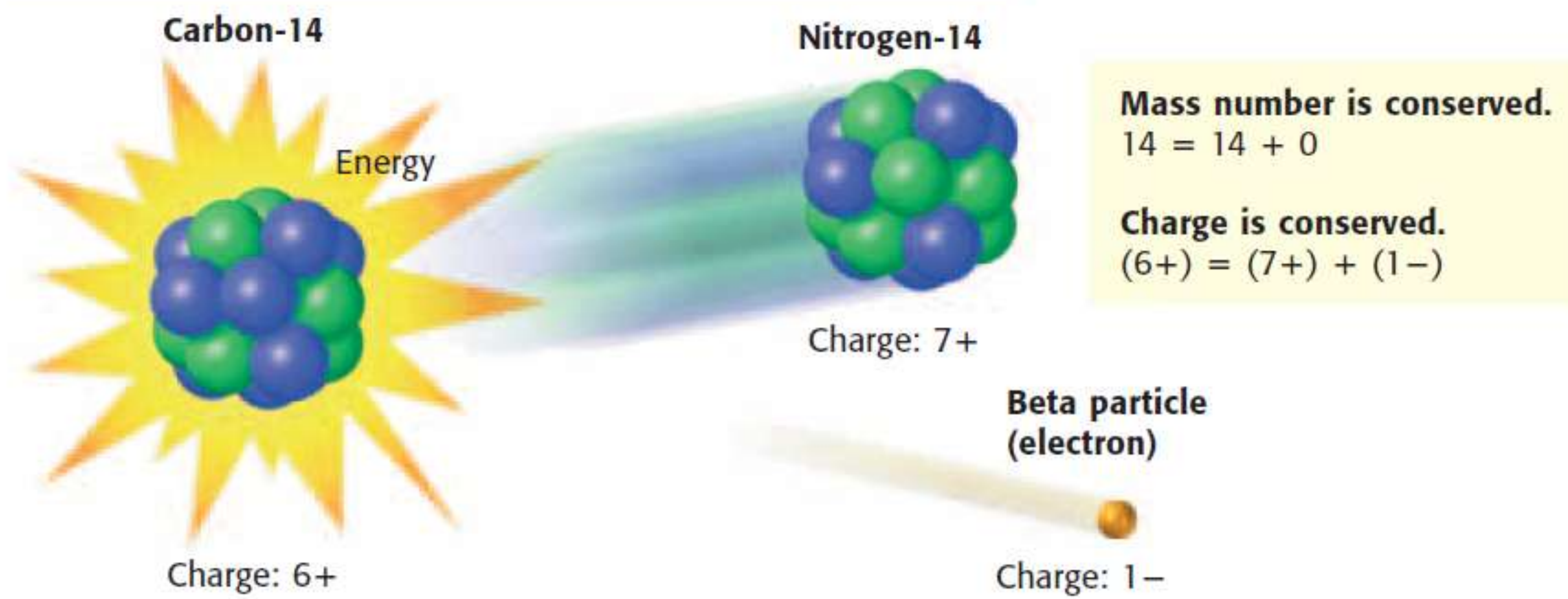
- 3 types of radioactive rays



16.1 Radioactivity

- 3 types of radioactive rays

Figure 3 Beta Decay of Carbon-14



16.1 Radioactivity

- 3 types of radioactive rays: energy is given off as <u>gamma rays</u> (high-energy light)

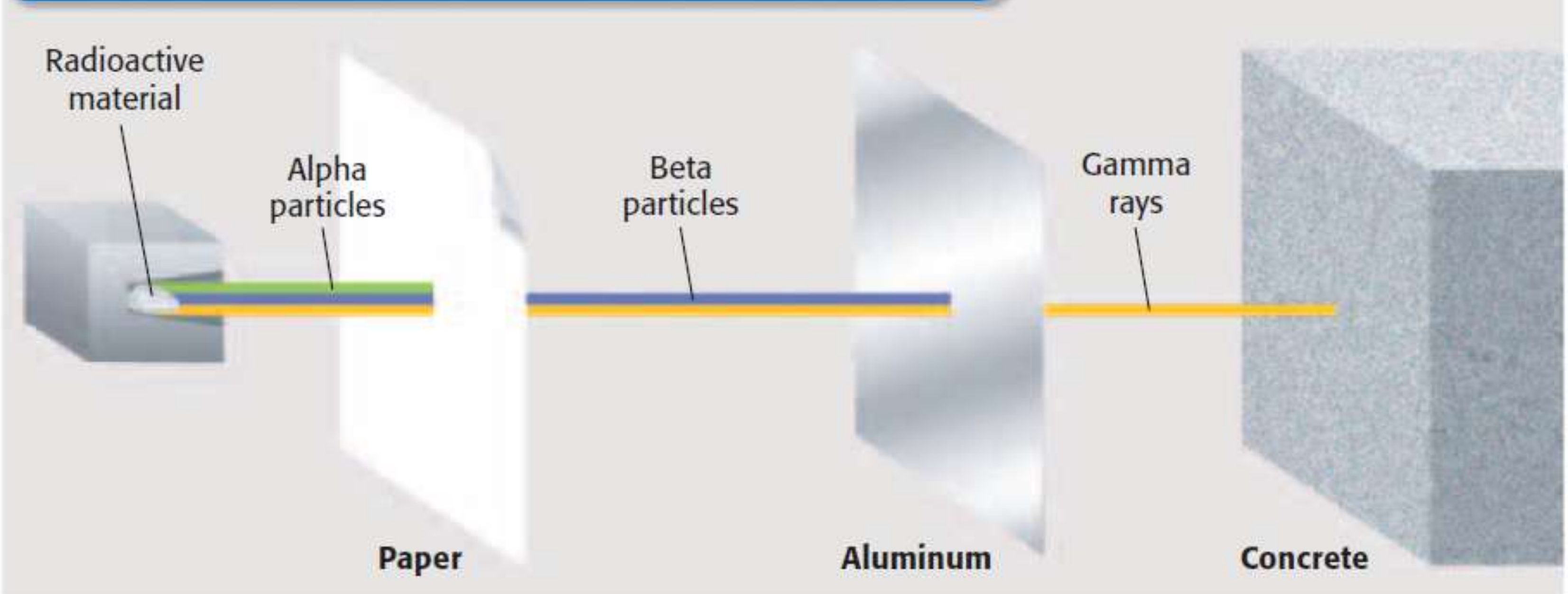


Figure 4 **The Penetrating Abilities of Nuclear Radiation**

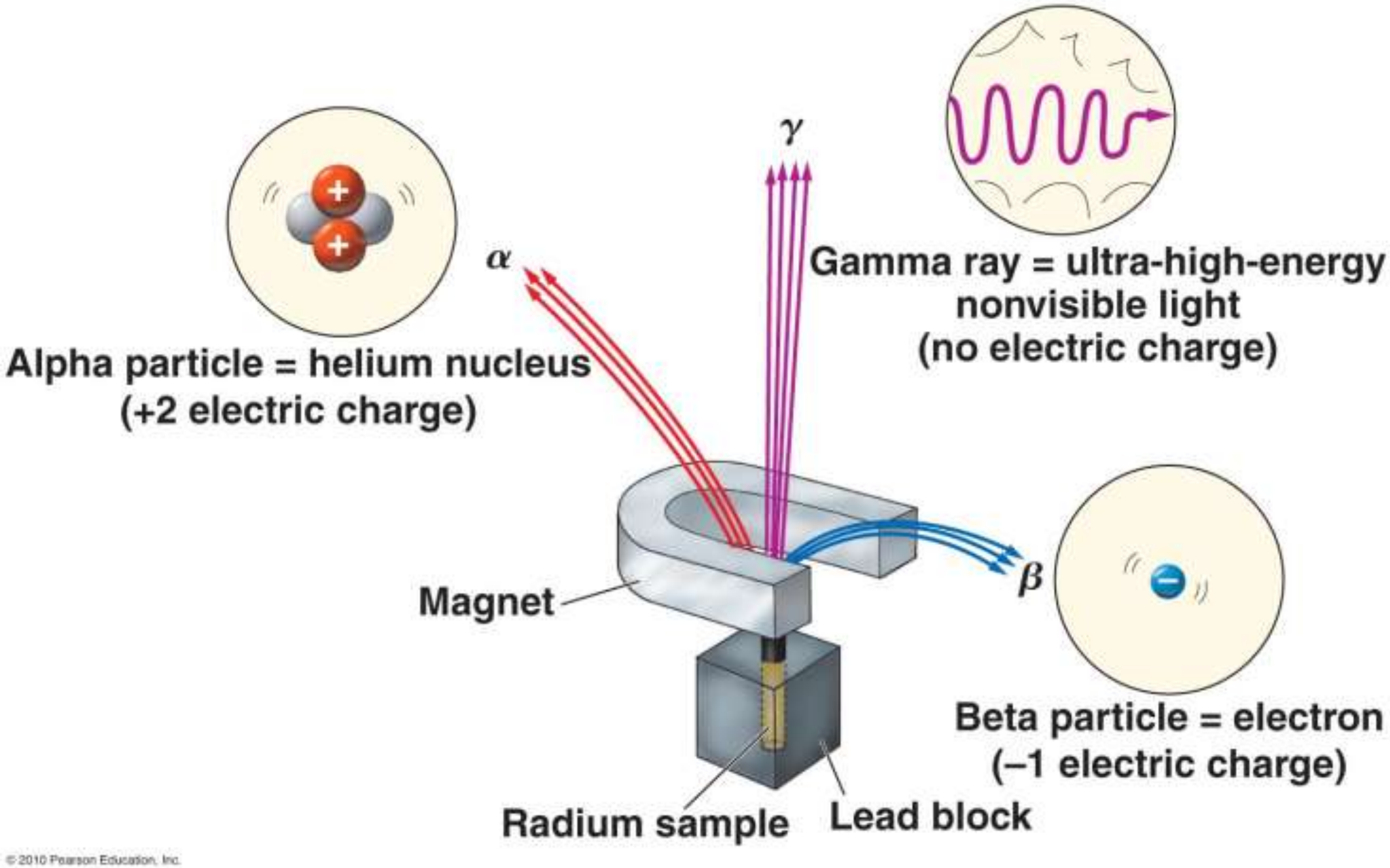
▲ **Alpha particles** have a greater charge and mass than beta particles and gamma rays do. Alpha particles travel about 7 cm through air and are stopped by paper or clothing.

▲ **Beta particles** have a 1– or 1+ charge and almost no mass. They are more penetrating than alpha particles. Beta particles travel about 1 m through air but are stopped by 3 mm of aluminum.

▲ **Gamma rays** have no charge or mass and are the most penetrating. They are blocked by very dense, thick materials, such as a few centimeters of lead or a few meters of concrete.

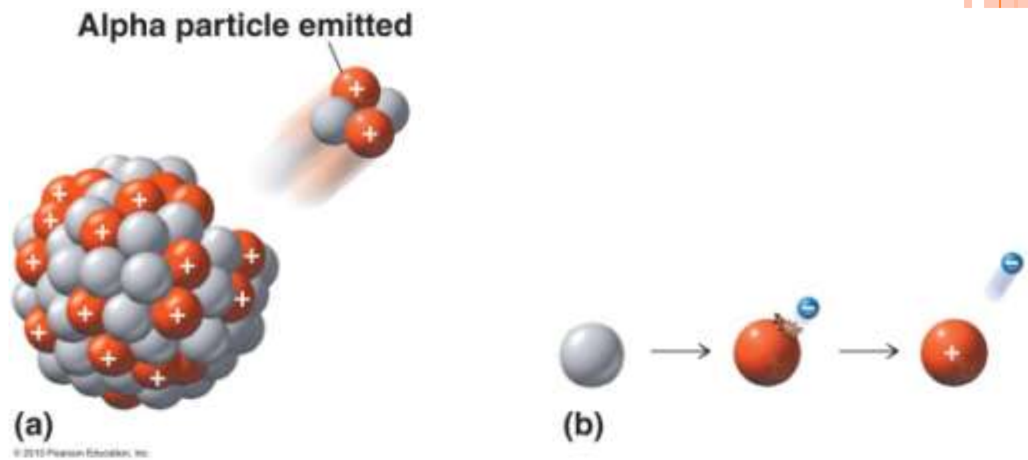
15.2 ALPHA, BETA, GAMMA RAYS

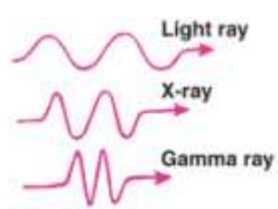
- Radioactive elements emit 3 types of radiation
- Which side is north or south? Would an electric field work?

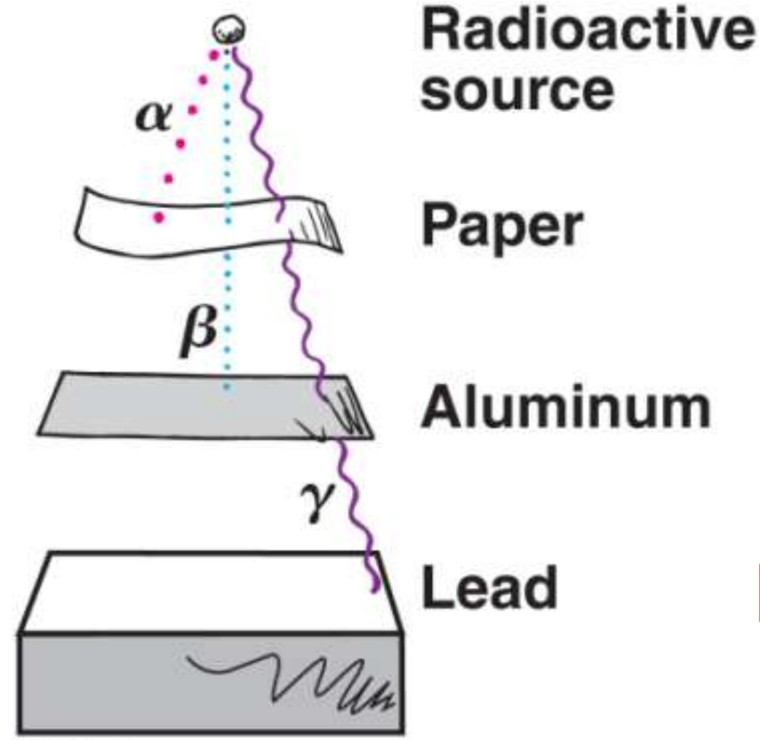


15.2 Alpha, Beta, Gamma Rays

- Radioactive elements emit 3 types of radiation
  - Alpha decay: emit helium nucleus and gamma radiation
    - Atomic number -2
    - Mass number -4
    - Easy to shield
  - Beta decay:
    - Neutron becomes proton and electron and neutral antineutrino
    - Enters aluminum and becomes part of the metal
  - Gamma rays:
    - Very high-frequency electromagnetic wave, photons.
    - Penetrates centimeters of lead

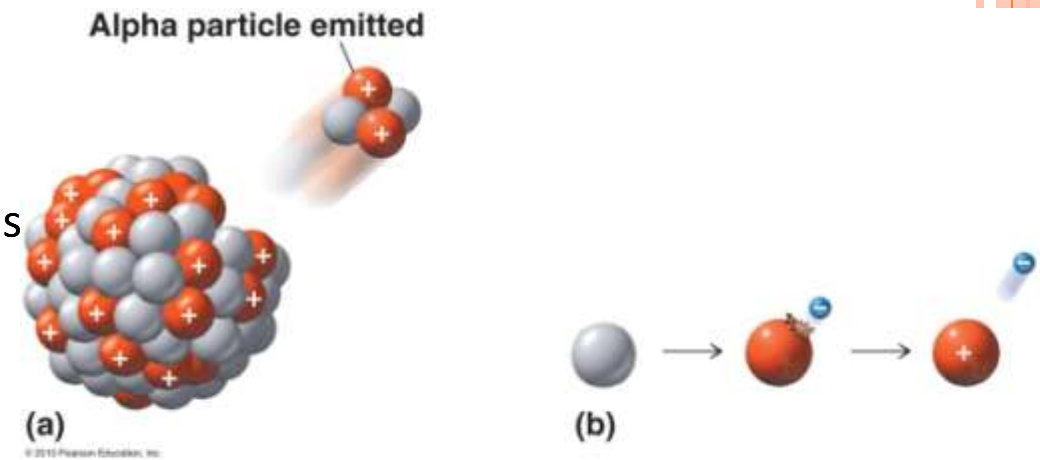


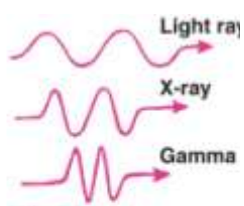


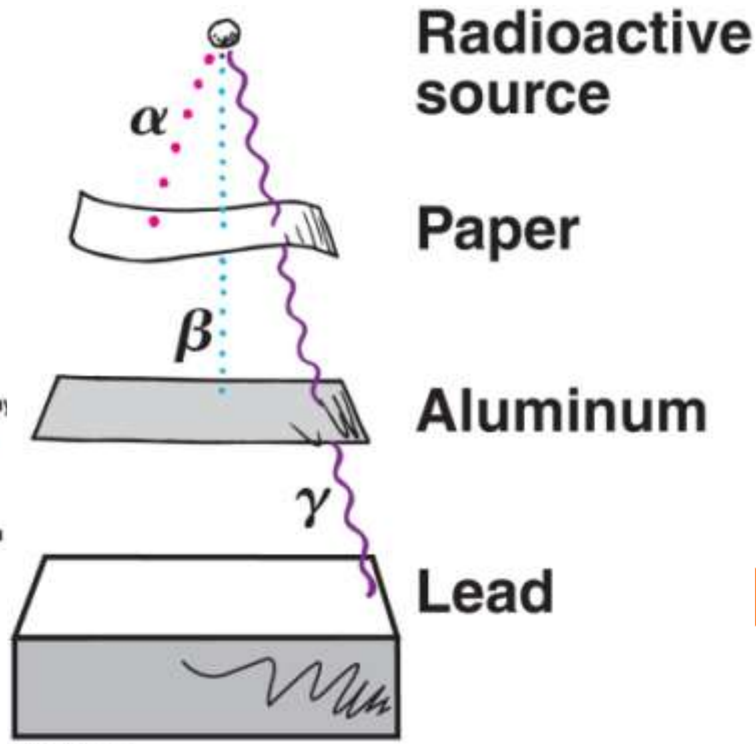


15.2 Alpha, Beta, Gamma Rays

- Radioactive elements emit 3 types of radiation
  - Alpha decay: emit helium nucleus and gamma radiation
    - easy to shield (large size and quickly neutralizes)
    - attracts 2 electrons quickly and becomes harmless helium (7% natural gas deposits in Texas is He)
    - when not slowed down yet, very damaging
  - Beta decay:
    - Neutron becomes proton and electron and neutral antineutrino
    - (Proton becomes neutron, positron and neutrino)
    - Electron enters aluminum and becomes part of the metal
  - Gamma rays:
    - Very high-frequency electromagnetic wave, photons.
    - Penetrates centimeters of lead







- http://www.youtube.com/watch?v=o-9yt7OAYmE&feature=related (1 minute. 3 types)

- You are given 3 radioactive rocks: alpha, beta, gamma.
  - Throw one away:
  - Hold one in your hand:
  - Put one in your pocket:

16.1 Radioactivity

- Effects of radiation

- On matter: atoms ionize

- On living matter: cell damage

- On nonliving matter: structures weaken

Radiation in the Environment

- Brick, stone houses (trace amounts of Uranium)
- Leading cause of lung cancer: Radon-222, inert heavy gas from Uranium deposits seep into basements.
- People and carbon-14 in plants

Coal industry	nuclear power plants
13000 tons radioactive thorium and uranium released into atmosphere. (Both found naturally in coal) Greenhouse gases	10000 tons annually Not released into environment

Radiation in the Body

- Carbon-14 from plants
- 200g Potassium
  - 20mg is radioactive potassium-40 (gamma ray emitter)
  - Between every heartbeat 5000 potassium-40 isotopes decay

- Cells can repair damage if radiation is spread out over a long time
- When radiation is big, some cells survive with damaged DNA, mutate… cancer

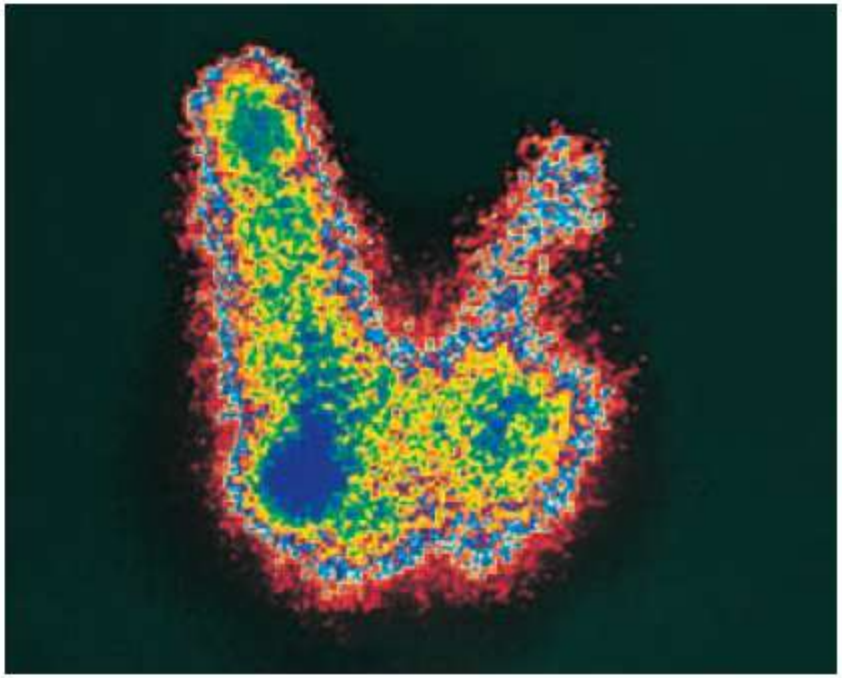
- 500 rems in a short time is 50% fatal

TABLE 10.1 ANNUAL RADIATION EXPOSURE

Source	Typical Amount Received in 1 Year (Millirems)
Natural Origin	
Cosmic radiation	26
Ground	33
Air (radon-222)	198
Human tissues (K-40; Ra-226)	35
Human Origin	
Medical procedures	
Diagnostic X-rays	40
Nuclear medicine	15
TV tubes and other consumer products	11
Weapons-test fallout	1

16.1 Radioactivity

Figure 7 **Uses of Radioactivity in Healthcare and in Industry**



Radioactive iodine-131 was used to make this scan of a thyroid gland. The dark area shows the location of a tumor.

Tracers are used to find weak spots in materials and leaks in pipes. A Geiger counter is often used to detect the tracer.

16.1 Radioactivity

- Uses of radioactivity
- Irradiated food

~gamma rays kill bacteria

- Extremophile
  - South African gold mine
  - Elevator 3.5 km down
  - 100% humidity
  - Rock temperature 60°C (140°F)
  - Bacteria live where no light, oxygen
  - food?
  - Radioactive decay of uranium!

Uses of Radiation

- Focus on harmful tissue – structural damage to molecules in cells

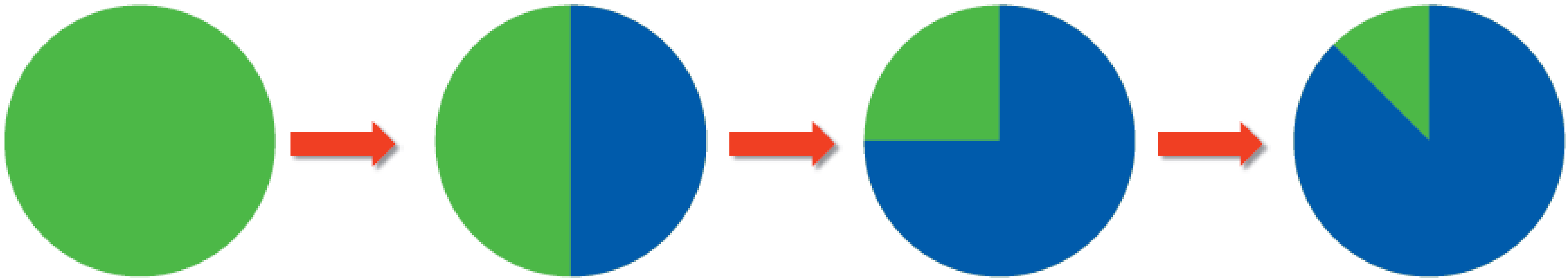
- Americium-241 makes air in smoke detector's ionization chamber electrically conductive. Smoke stops current, alarm sounds.

16.1 Radioactivity

- Radioactive dating
  - half life = time for half the matter to decay into another element
  - shorter half-life, more radiation emitted.
  - amount present ~ rate of radiation emission. Measure rate by Geiger counter.
- How old?
  - Carbon-dating: up to ________________ years old
  - Potassium-dating : up to ________________ years old
- How did scientists age the Ice Man?
  - All living things contain _____________ atoms
  - Some of these are _________________ atoms that are "refilled" during life.

16.1 Radioactivity

- If 1 half-life d= 5 seconds, then how much time has gone by?



15.5 Half-Life

- Exponential growth and decay model

- k = decay constant. Geiger counter

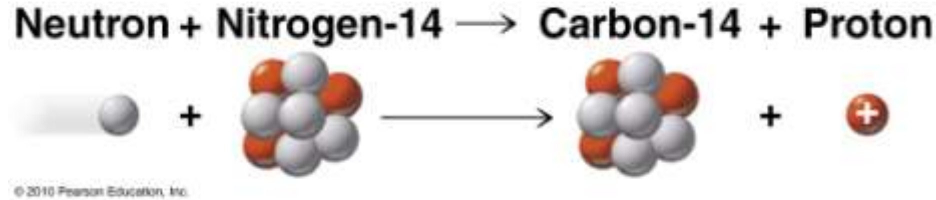
Bonus

- Pg. 285
  - Radium-226 has a half-life of 1620 years
  - Mathematical model
  - Verify in 2 ways that it takes 20 half-lives to decay to one-millionth the initial amount.

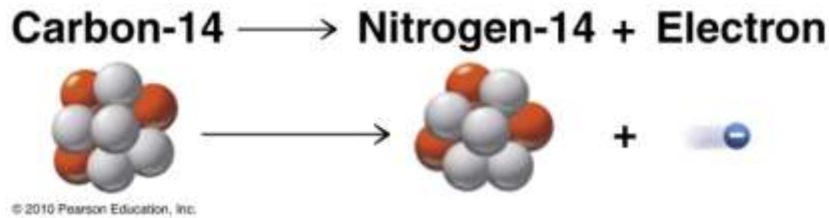
- If a radioactive isotope has a half-life of 1 day, how much of the original sample will remain at the end of the second day? The third day?

- Which will give a higher counting rate on a radiation detector – radioactive material that has a short half-life or a long half-life?

Isotopic Dating



- Nitrogen in atmosphere is bombarded by cosmic rays



- Carbon-14 radioactive isotope is one-millionth of 1% of the carbon in the atmosphere. Carbon-12 is more common. Both chemically react with oxygen to form carbon-dioxide.
  - Plants
  - Carbon-14 is 1 in every 100 billion Carbon-12 in living things.
  - When a tree dies, carbon-12 remains constant, but the carbon-14 decays with half-life **5730**.
  - Carbon-14 dating can go back 50000 years. Why?
  - Accuracy 15%

- A wooden handle contains 1/8 of the carbon-14 compared to a fresh tree branch. How old is the handle?

  (half-life = 5730 years)

- A radioisotope is placed near a radiation detector, which registers 80 counts per second. Eight hours later, the detector registers 5 counts per second. What is the half-life of the radioactive isotope?

16.1 Radioactive dating

Table 1 Examples of Half-Lives

Isotope	Half-life	Isotope	Half-life
Uranium-238	4.5 billion years	Polonium-210	138 days
Oxygen-21	3.4 s	Nitrogen-13	10 min
Hydrogen-3	12.3 years	Calcium-36	0.1 s

- Take out a sheet of paper.

Start with 64 grams of Nitrogen-13.

a) Fill in this table

b) Draw a graph of the amount of Nitrogen

100 minutes.

MATH PRACTICE

How Old Is It?

One-fourth of the original carbon-14 of an antler is unchanged. As shown in **Figure 6,** two half-lives have passed. To determine the age of the antler, multiply the number of half-lives that have passed by the half-life of carbon-14. The antler's age is 2 times the half-life of carbon-14:

$$\text{age} = 2 \times 5{,}730 \text{ years}$$
$$\text{age} = 11{,}460 \text{ years}$$

Determine the age of a wooden spear that contains one-eighth of its original amount of carbon-14.

les of Half-Lives		
Half-life	Isotope	Half-life
4.5 billion years	Polonium-210	138 days
3.4 s	Nitrogen-13	10 min
12.3 years	Calcium-36	0.1 s

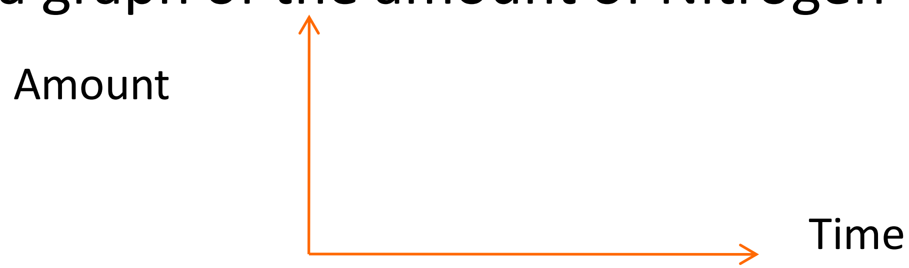
Time (minutes)	Amount of Nitrogen-13(grams)
0	64
10	
20	
30	
40	
…	
100	

- Take out a sheet of paper.

Start with ***<u>64 grams</u>*** of Nitrogen-13.

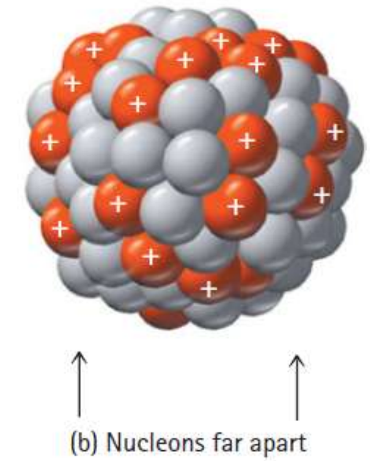
a) Fill in this table

b) Draw a graph of the amount of Nitrogen-13 over 100 minutes.



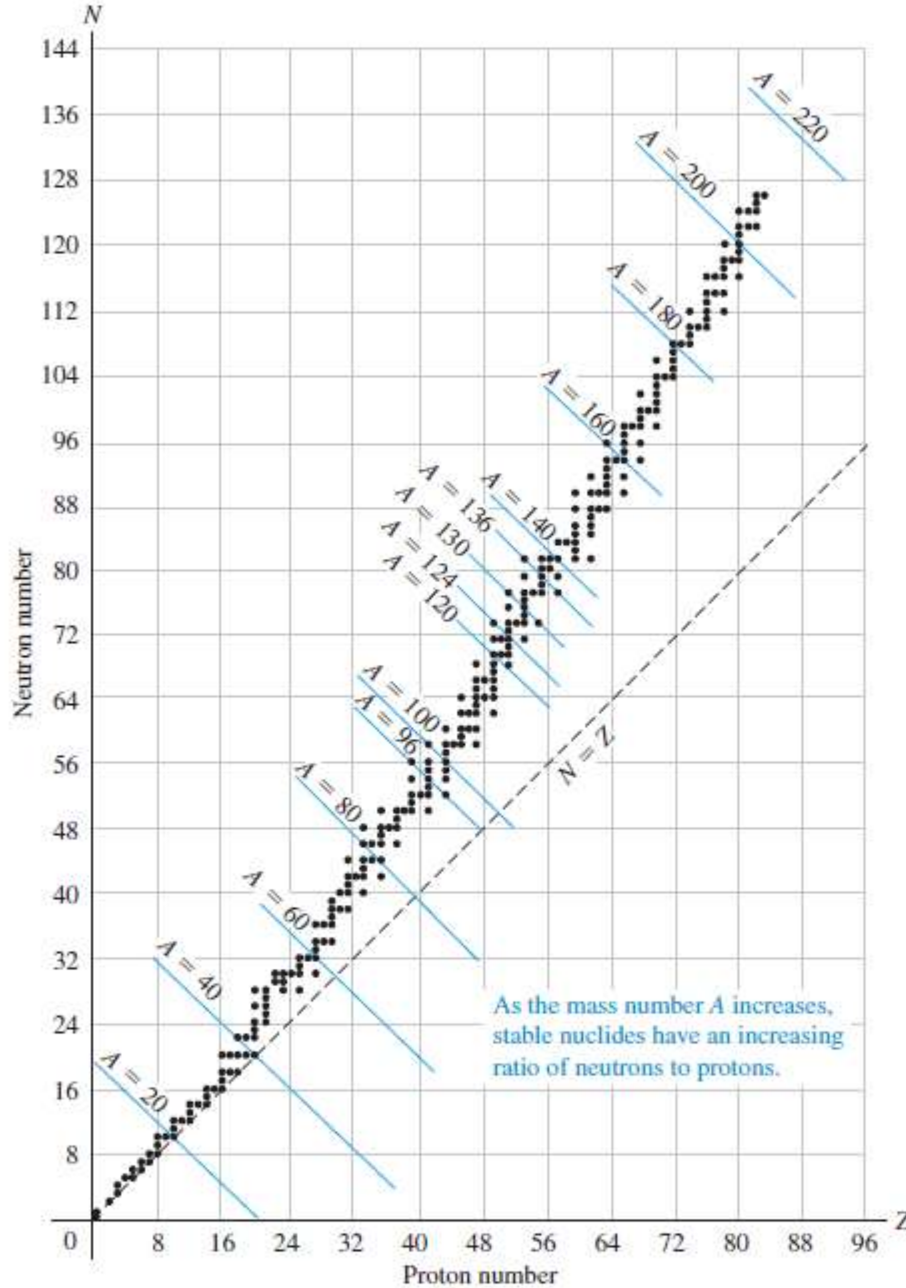
c) What is this type of graph called?

Strong Nuclear Force



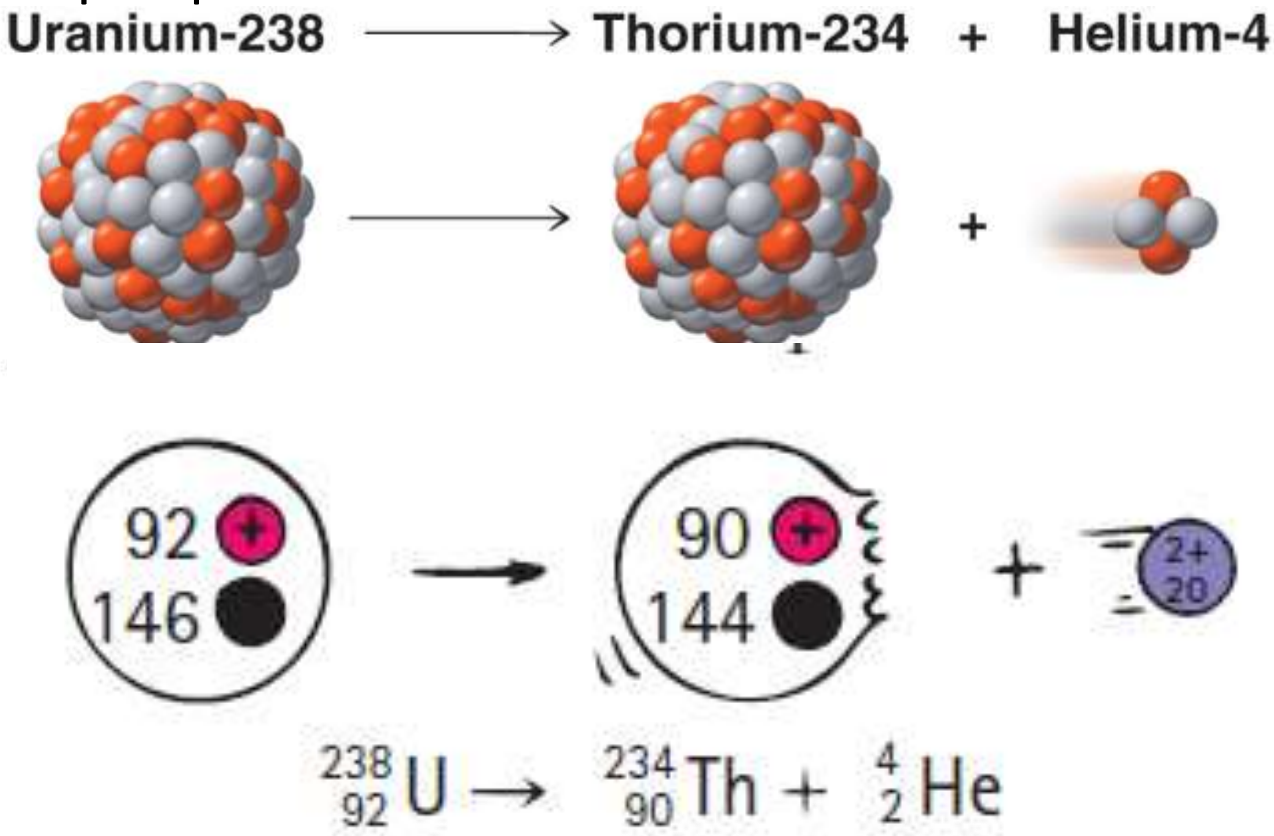
- Why decay? What makes a nucleus unstable?
- Strong force between nucleons ~ 10^-15 m.
- Electrical force is farther in range.
- Large nuclei are unstable since nucleons at edges could have more electrical repulsion than strong attraction.
- Protons repel. Neutrons are like glue. (strong only, 0C)
- A neutron by itself is unstable → proton + electron (beta decay)
- A neutron needs neighbor protons to ‘stay together’.
- Big nuclei don’t have enough protons to keep the neutrons “together”. Neutron decays. Too many protons now repel → split

- Protons repel. Neutrons are like glue. (strong only, 0C)
- Bigger size, more neutrons needed



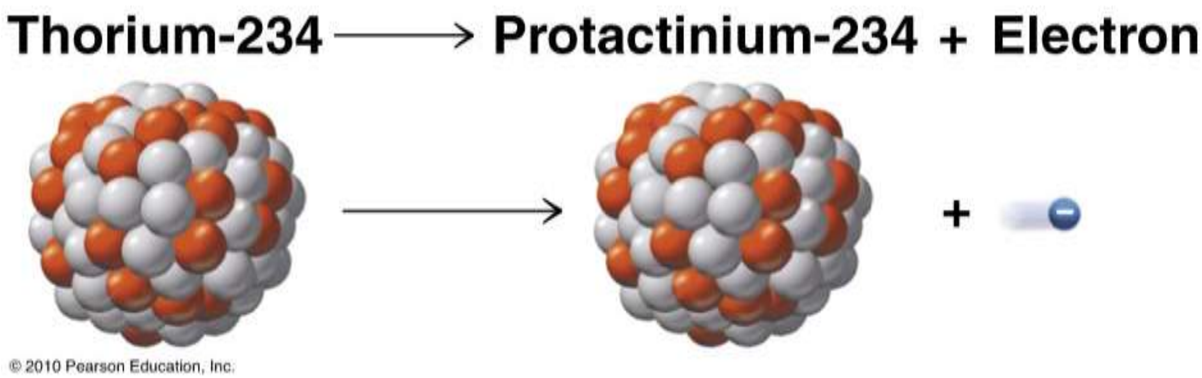
EXTRA: TRANSMUTATION OF ELEMENTS

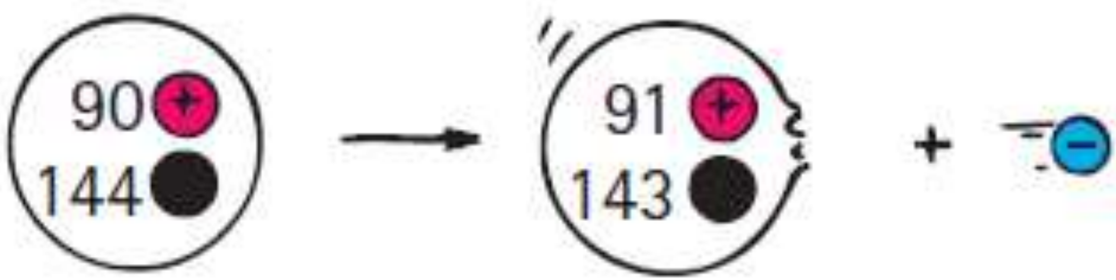
- Alpha-decay: energy released as gamma radiation and KE of alpha particle and recoil of Thorium



EXTRA: TRANSMUTATION OF ELEMENTS

- Beta-decay

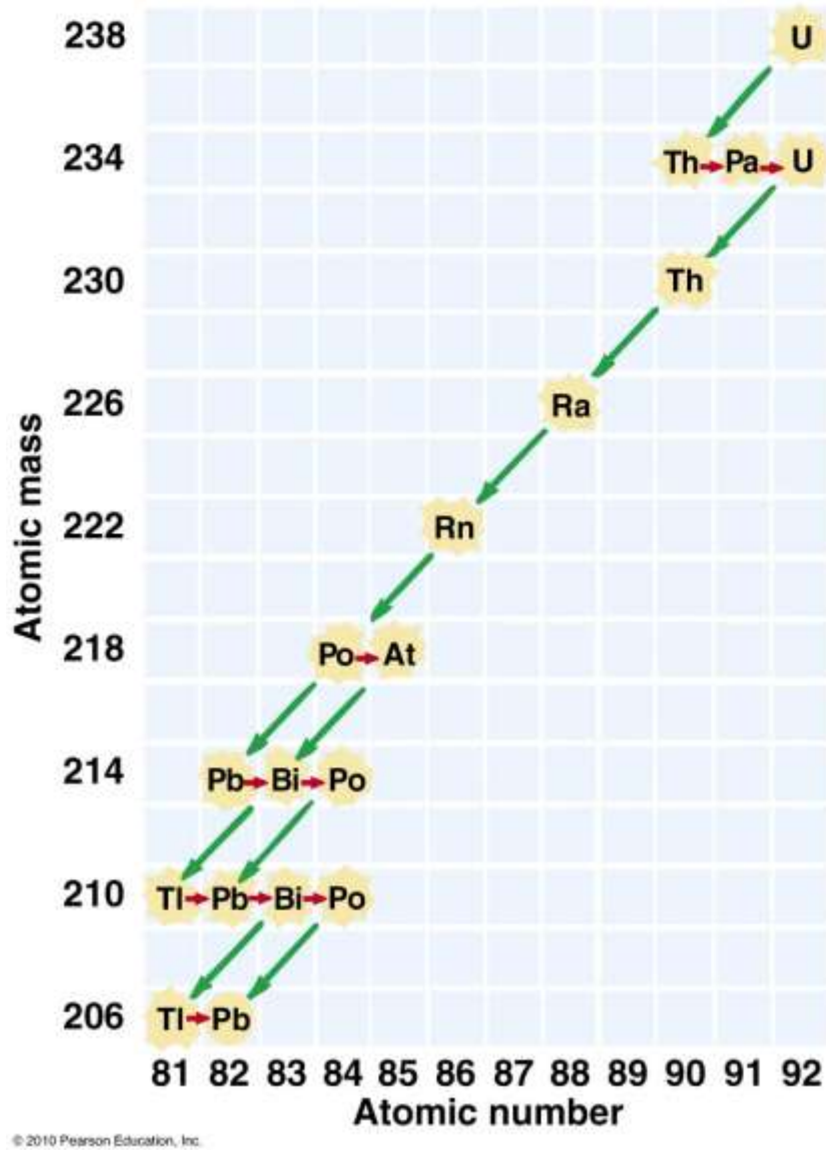




$$^{234}_{90}\mathrm{Th} \rightarrow {}^{234}_{91}\mathrm{Pa} + {}^{0}_{-1}\mathrm{e}$$

EXTRA: TRANSMUTATION OF ELEMENTS

- What does Uranium finally become?



Transmutation: Practice Book Hint

- U-238 becomes Pb-206
- U-235 becomes Pb – 207
- But the most common is Pb-208.

TRANSMUTATION

- Ernest Rutherford (1919) was the first to show transmutation.

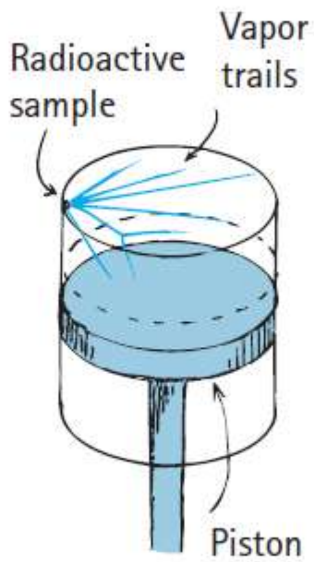
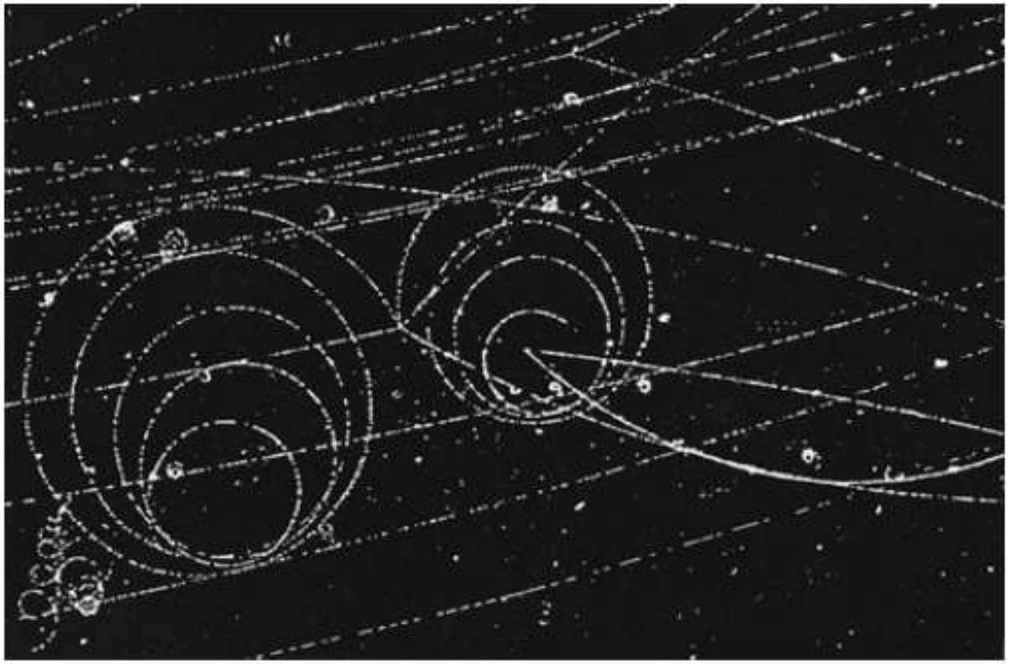


FIGURE 10.18
A cloud chamber. Charged particles moving through supersaturated vapor leave trails. When the chamber is in a strong electric or magnetic field, the bending of the tracks provides information about the charge, mass, and momentum of the particles.



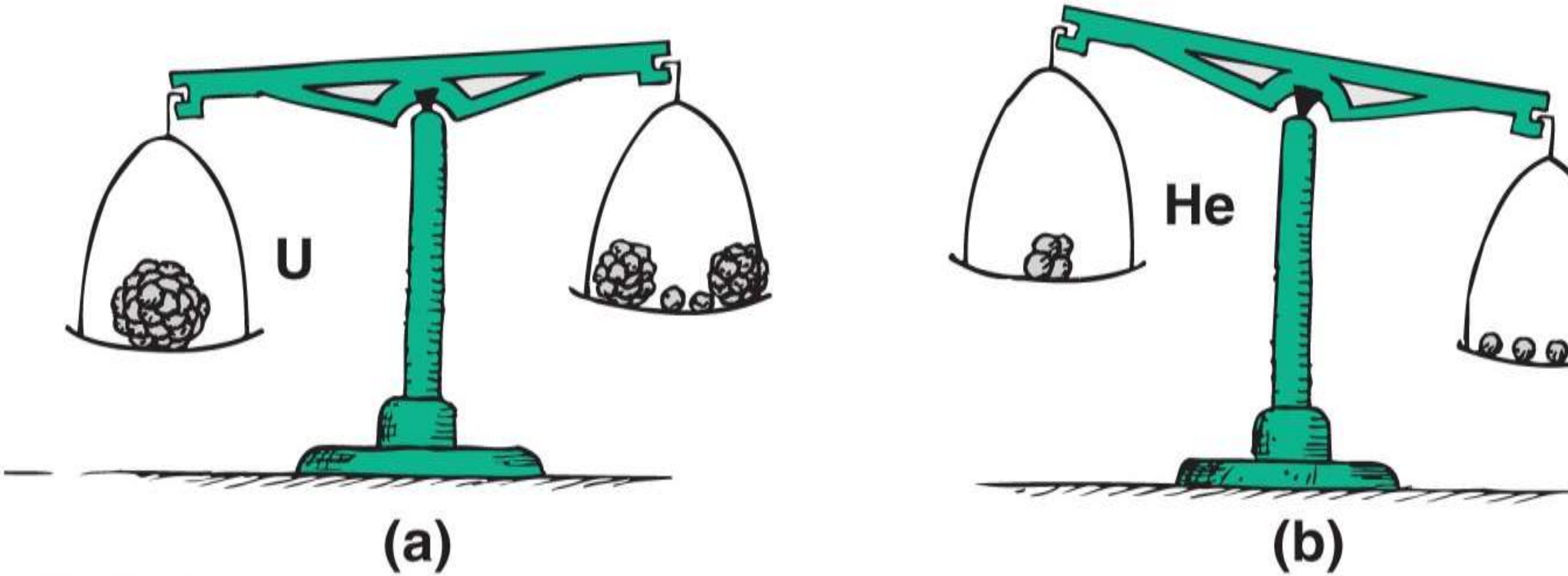
16.2 Nuclear Energy?

- 1938 Otto Hahn and Fritz Strassmann bombarded uranium with neutrons, trying to create a heavier element. They found barium.
- Lise Meitner concluded the uranium had split in half (fission)

16.2 Nuclear Energy?

$E = mc^2$

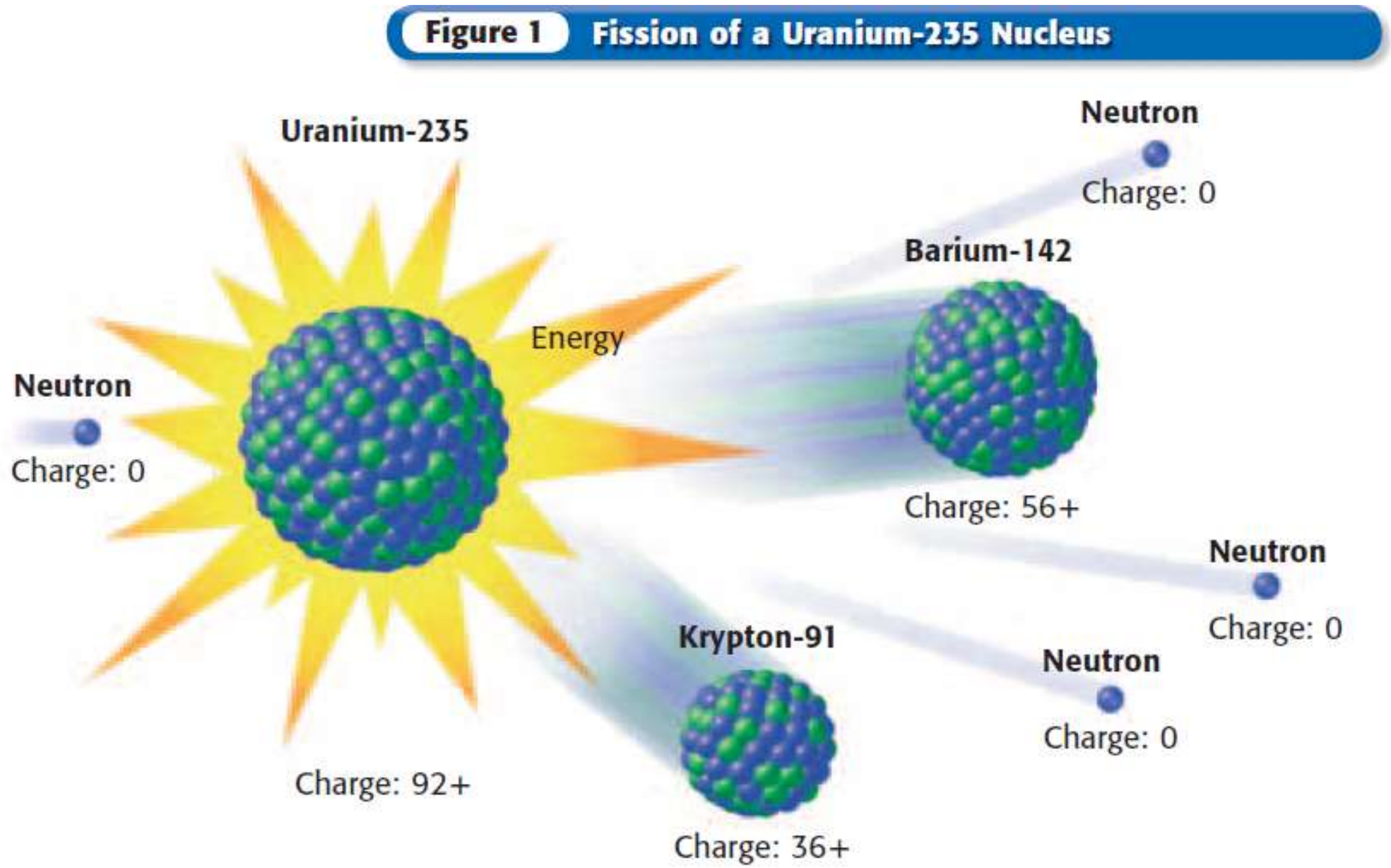
Mass is energy!



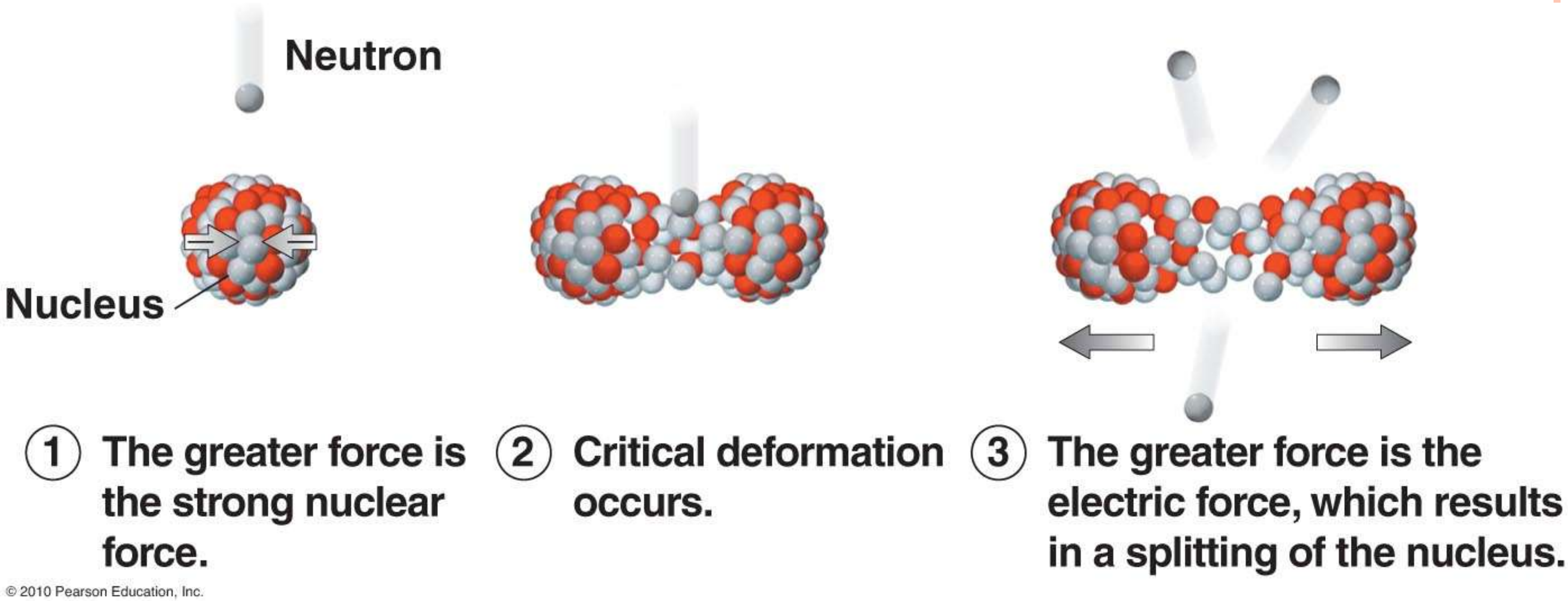
- Fission or fusion?

16.2 Nuclear Energy

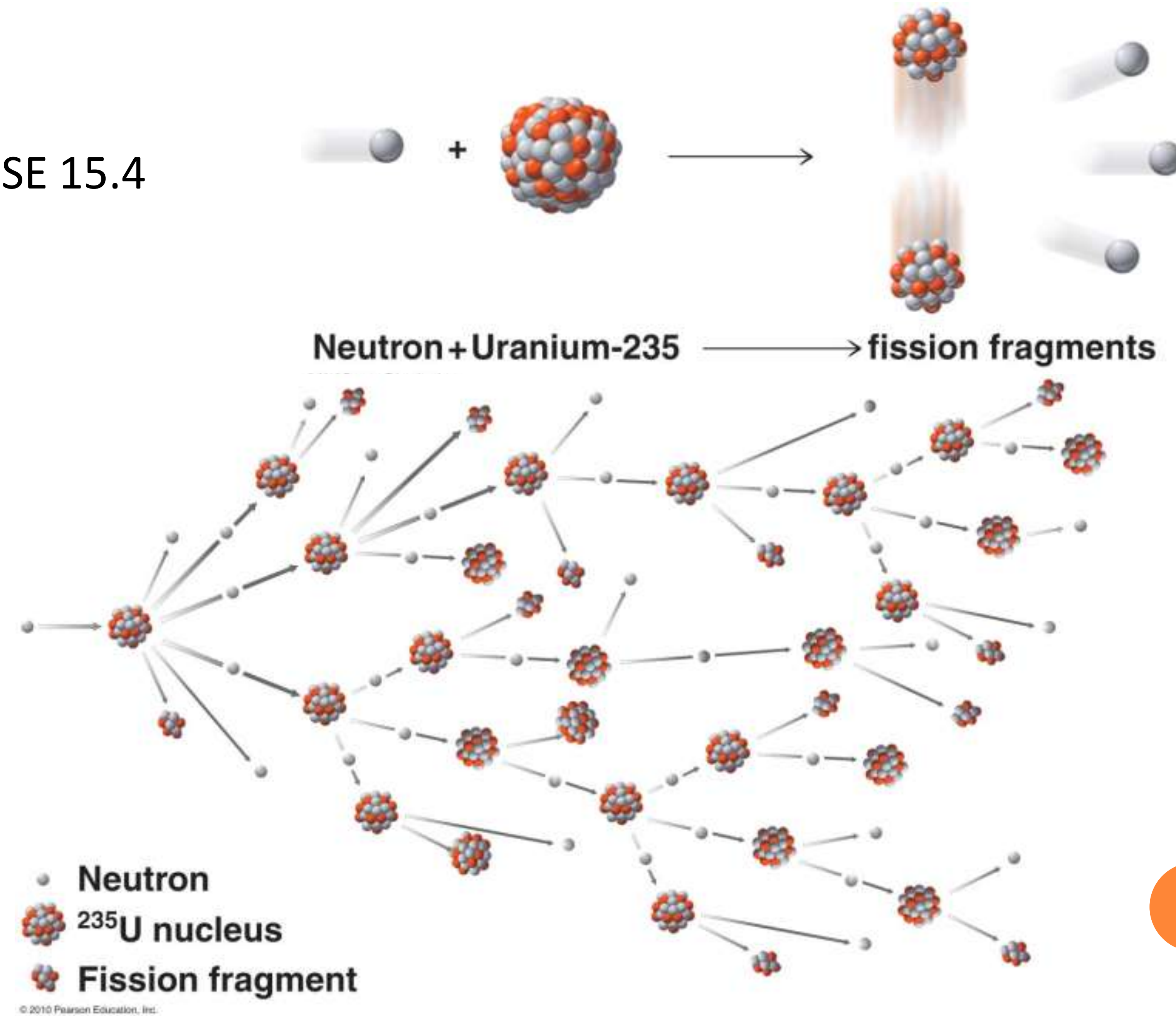
- Fission = when ______________________
- Draw a picture of fission:



15.6 Nuclear Fission



- CISE 15.4

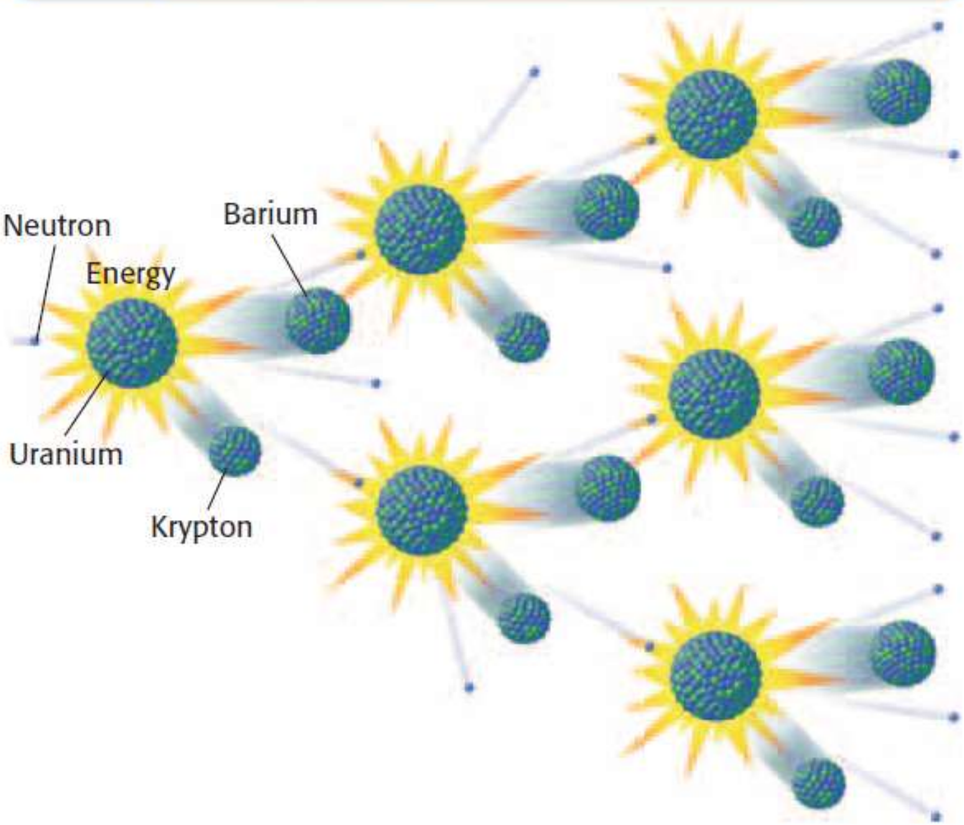


+
Neutron + Uranium-235 → fission fragments
Neutron
^{235}U nucleus
Fission fragment
© 2010 Pearson Education, Inc.

16.2 Nuclear Energy

- Uncontrolled chain reaction…?
- http://www.youtube.com/watch?v=9HJD-Il9_4g&feature=related
- 7th s
- Part
- Part ford and gol
- Part ap

Figure 3 An Uncontrolled Nuclear Chain Reaction

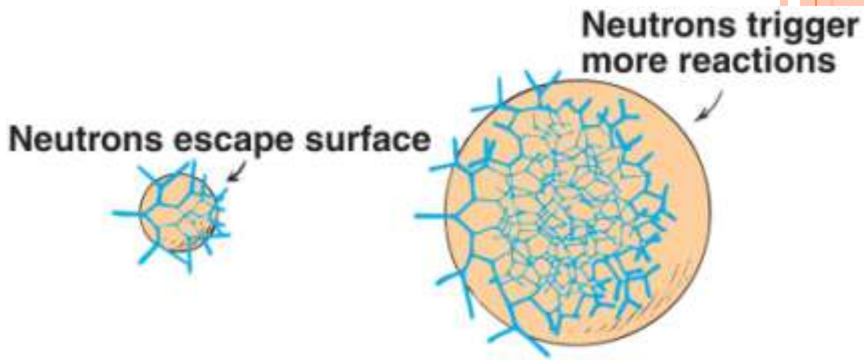


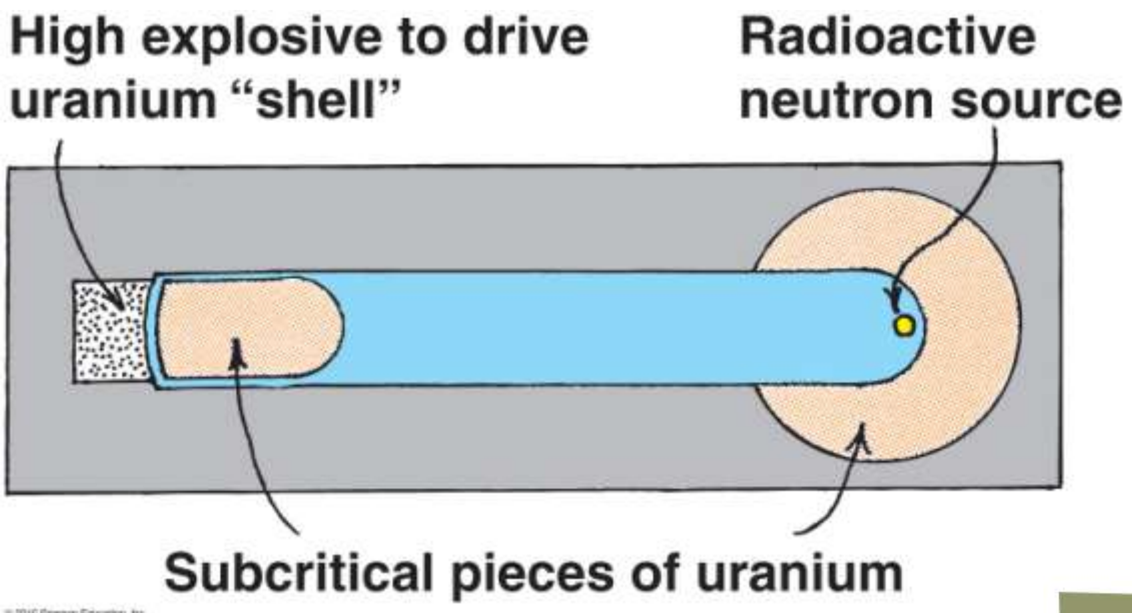
CHAIN REACTION?

- U-235 easily undergoes fission.
- However
  - U-235 is less than 0.7% of naturally occurring uranium (mostly U-238)
  - U-238 and other rocks absorb any neutrons released by U-235.
- 1945 Hiroshima and Nagasaki
  - It took over 2 years to extract (enrich) U-235 from U-238 in uranium ore.

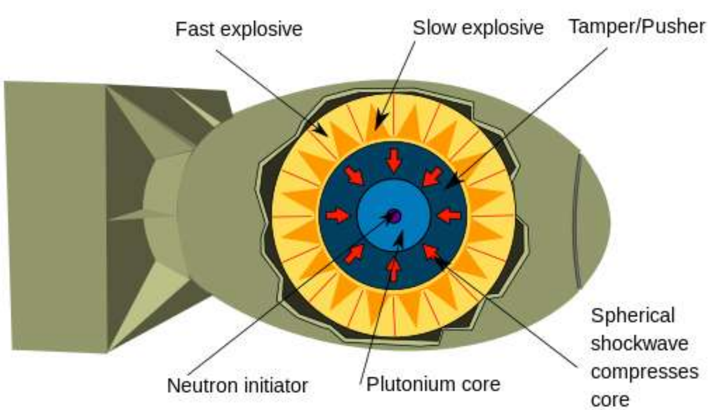
Chain reaction critical mass

- sub-critical to super-critical mass
- gun-type, implosion type



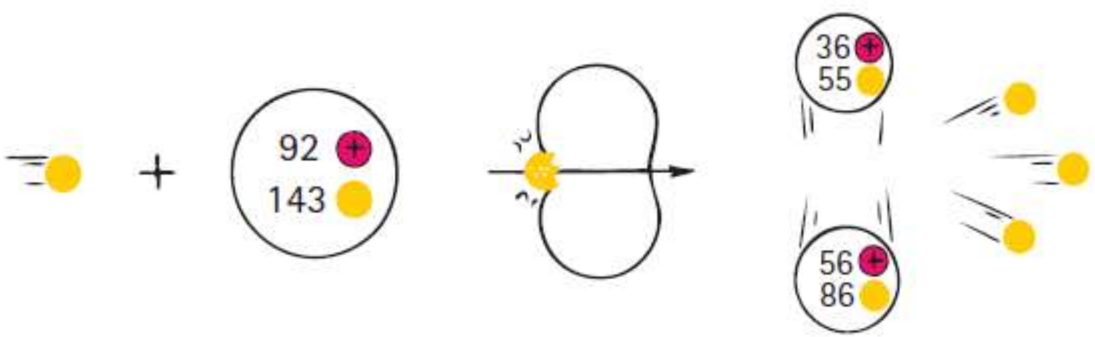


- U-235 and Pu-239



- fission bomb = atomic bomb
- Fusion bomb = thermonuclear or H-bomb 1952
  - fission can be used to create temperatures near 10^8 K for uncontrolled fusion.
  - 1000 times more destructive than the atomic bomb

ypical uranium fission reaction is



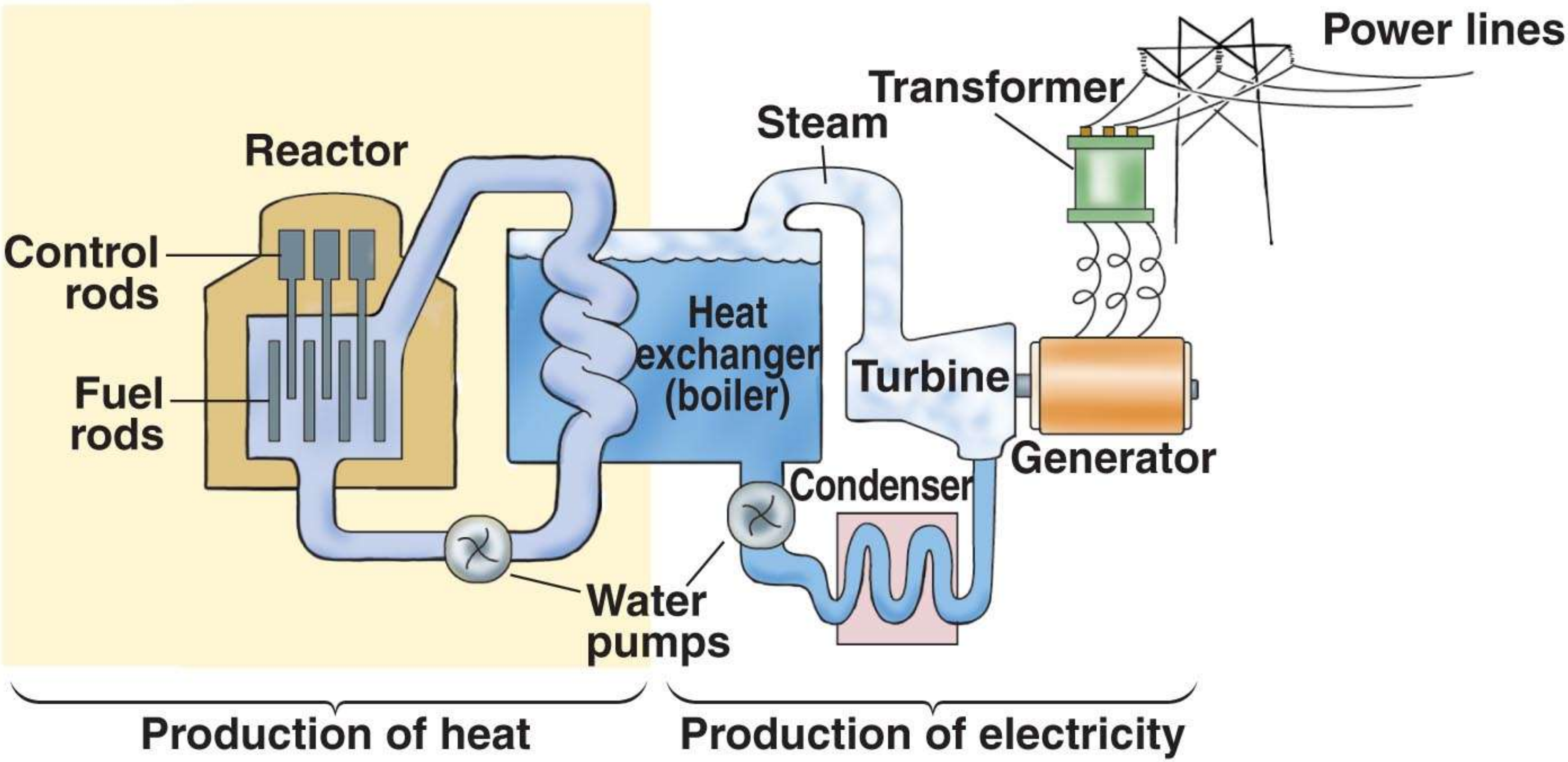
$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{91}_{36}Kr + ^{142}_{56}Ba + 3(^{1}_{0}n)$$

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + ^{1}_{0}n + 3.26\text{ MeV}$$

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + 17.6\text{ MeV}$$

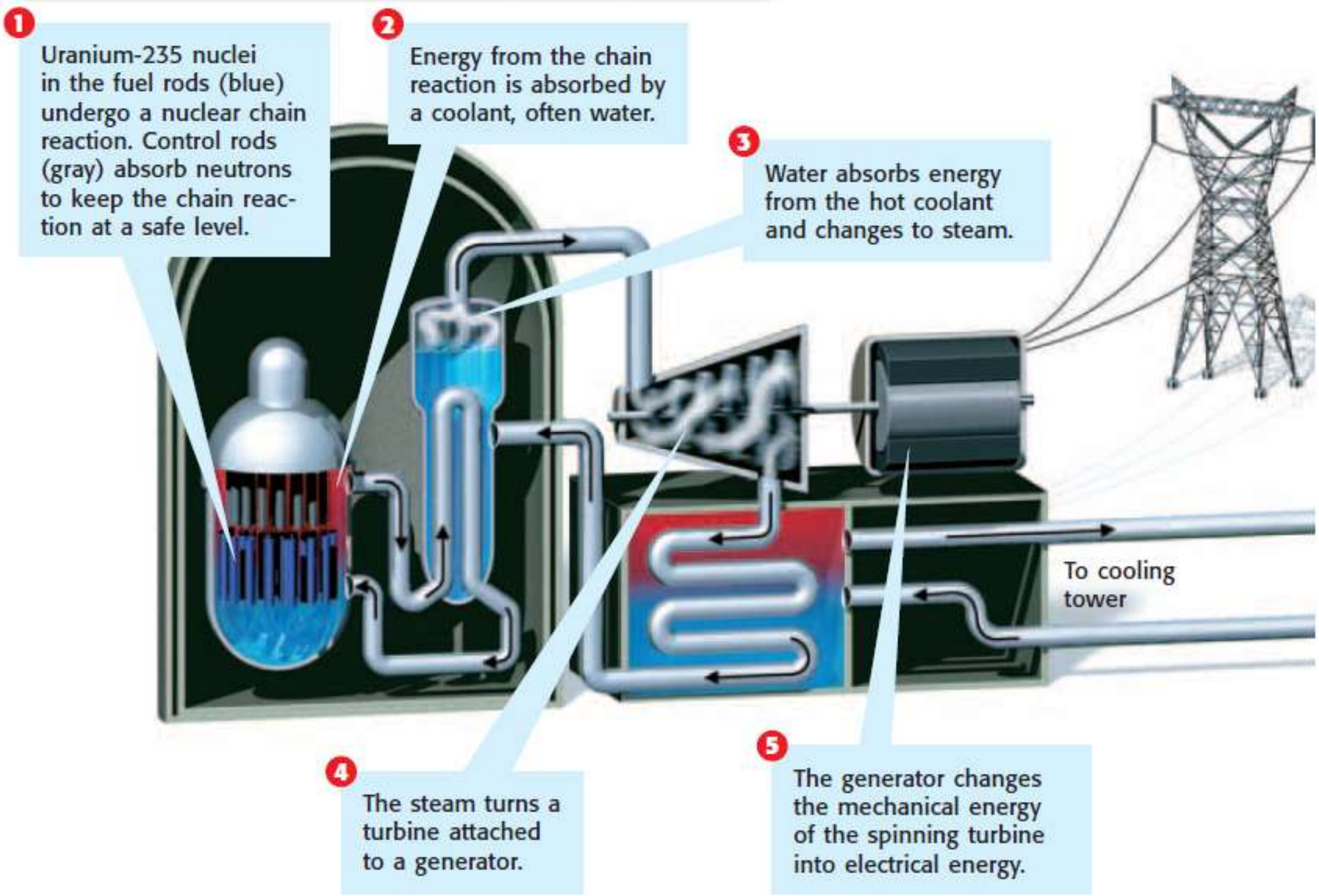
FIGURE 10.34
Fusion reactions of hydrogen isotopes. Most of the energy released is carried by the neutrons, which are ejected at high speeds.

Controlled Chain Reaction (Fission)



16.2 Nuclear Energy

- Controlled chain reaction…?



Controlled Chain Reaction

- Challenges
  - Nucleus will absorb slow neutrons best: moderator slows down the fast neutrons emitted during fission. (heavy water, deuterium H-2, is the best moderator)
  - enrich enough U-235
  - maintain near-critical mass using control rods to absorb neutrons.

- Problems
  - disposing radioactive fission fragments (plutonium half-life is 24000 years)
  - radioactive pieces also weaken the reactor structure. Lifetime ~ 30 years. High cost of "decommissioning"
  - enrichment and theft for bomb fuel
  - Radioactive fallout (from fission bomb) -- radioactive isotopes in atmosphere settle to Earth in rainfall, absorbed by plants, enter food chain. Much worse than outside skin. E.g. strontium-90 is chemically like calcium and concentrates in bone, causing cancer.

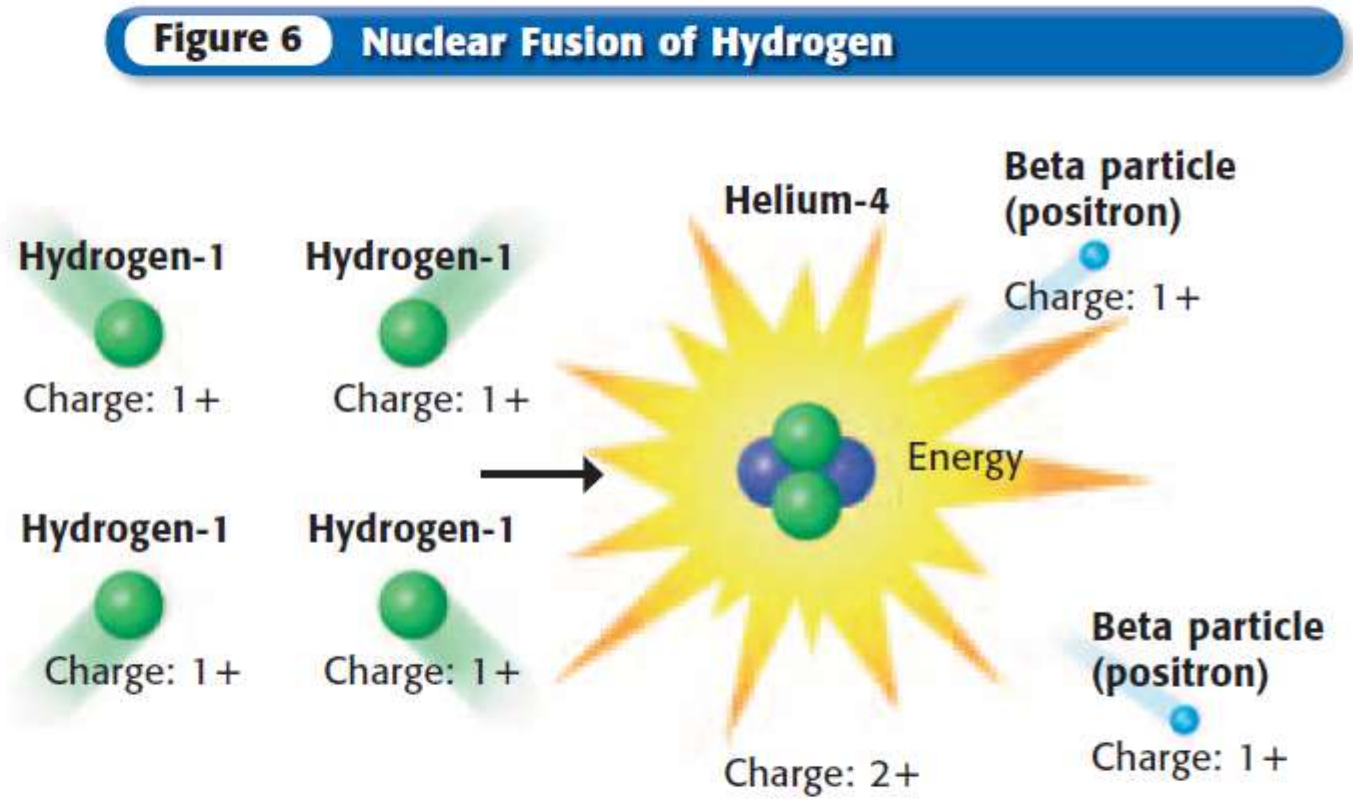
16.2 Nuclear Energy

- Nuclear power plants:

Pros	Cons
•1 pellet = 1000 kg coal! •Less pollution in air  **Figure 2** *Each of these small fuel pellets can generate a large amount of energy through the process of nuclear fission.*	 •50 year use → thousand- year waste •Limited supply of uranium

16.2 Nuclear Energy

- Fusion = when ....?
- Draw a picture of fusion:



16.2 Nuclear Energy

- Nuclear fusion

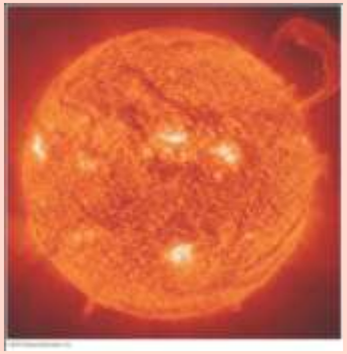
Because [+][-] charged nuclei [attract][repel], getting them to fuse requires [low][high] temperature > __________________ ^{o} C.

At this temperature, matter is ___________________.

Draw a picture of plasma:

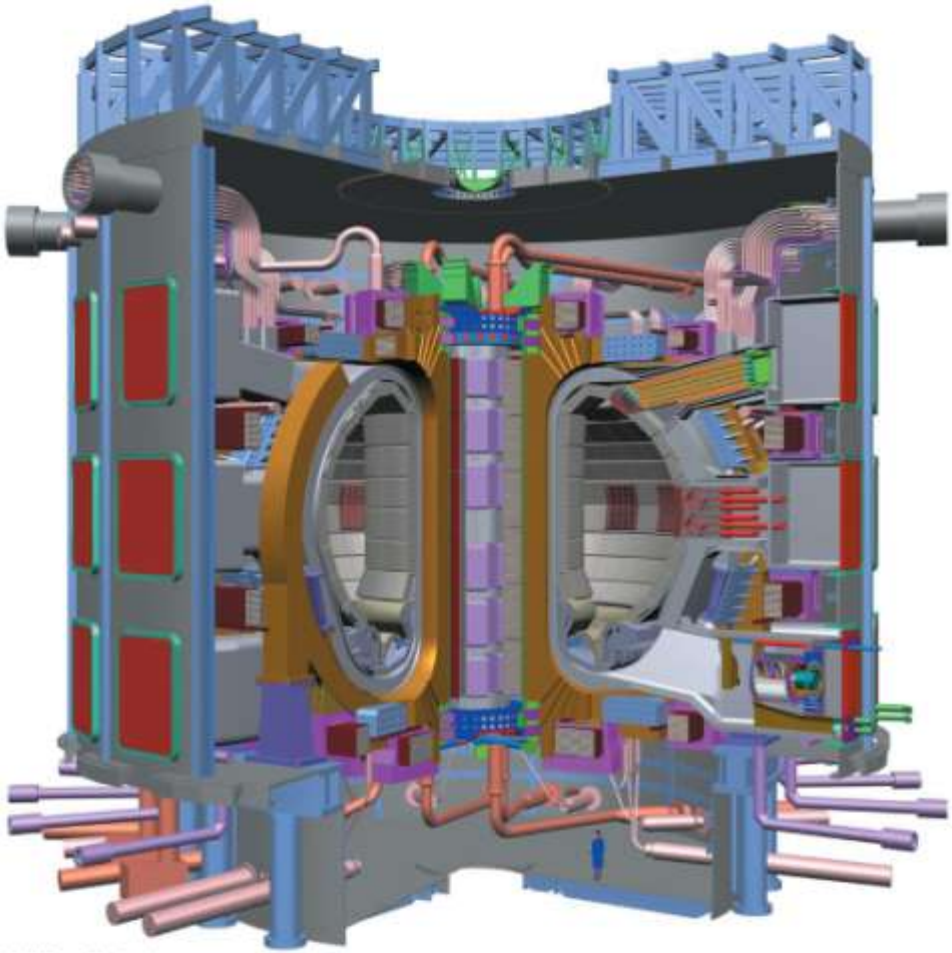
16.2 Nuclear Energy

- Fusion energy ~in the future!
-

Pros	Cons
 **Figure 7** *Fusing the hydrogen-2 in 3.8 L of water would release about the same amount of energy as burning 1,140 L of gasoline!* • non-radioactive fusion products •Hydrogen is 90% of all elements	

16.2 Nuclear Energy

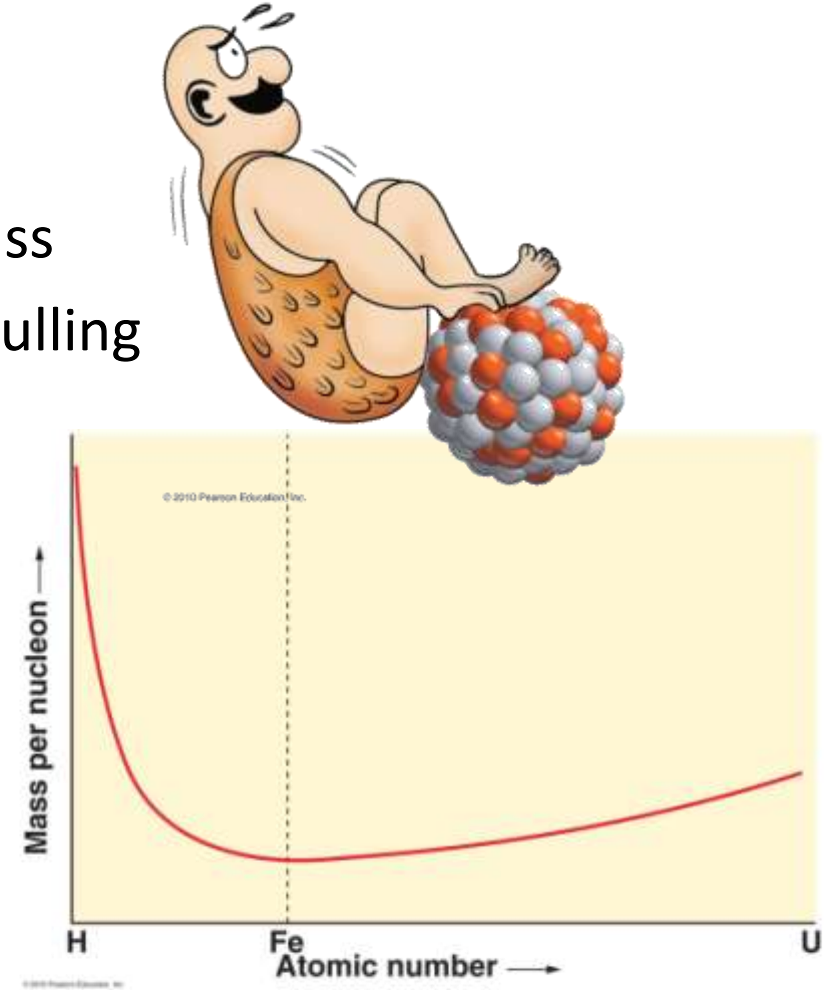
- A fusion reactor in progress. Vaporize. Use Magnetic confinement.
- International Thermonuclear Experimental Reactor (ITER) France ~~2015~~, 2019 (built), 2027 (full-scale experiments)



$E=mc^2$

- Looser nucleons have bigger mass

by gaining the work you put into pulling



- H is a single proton.

There's no binding energy

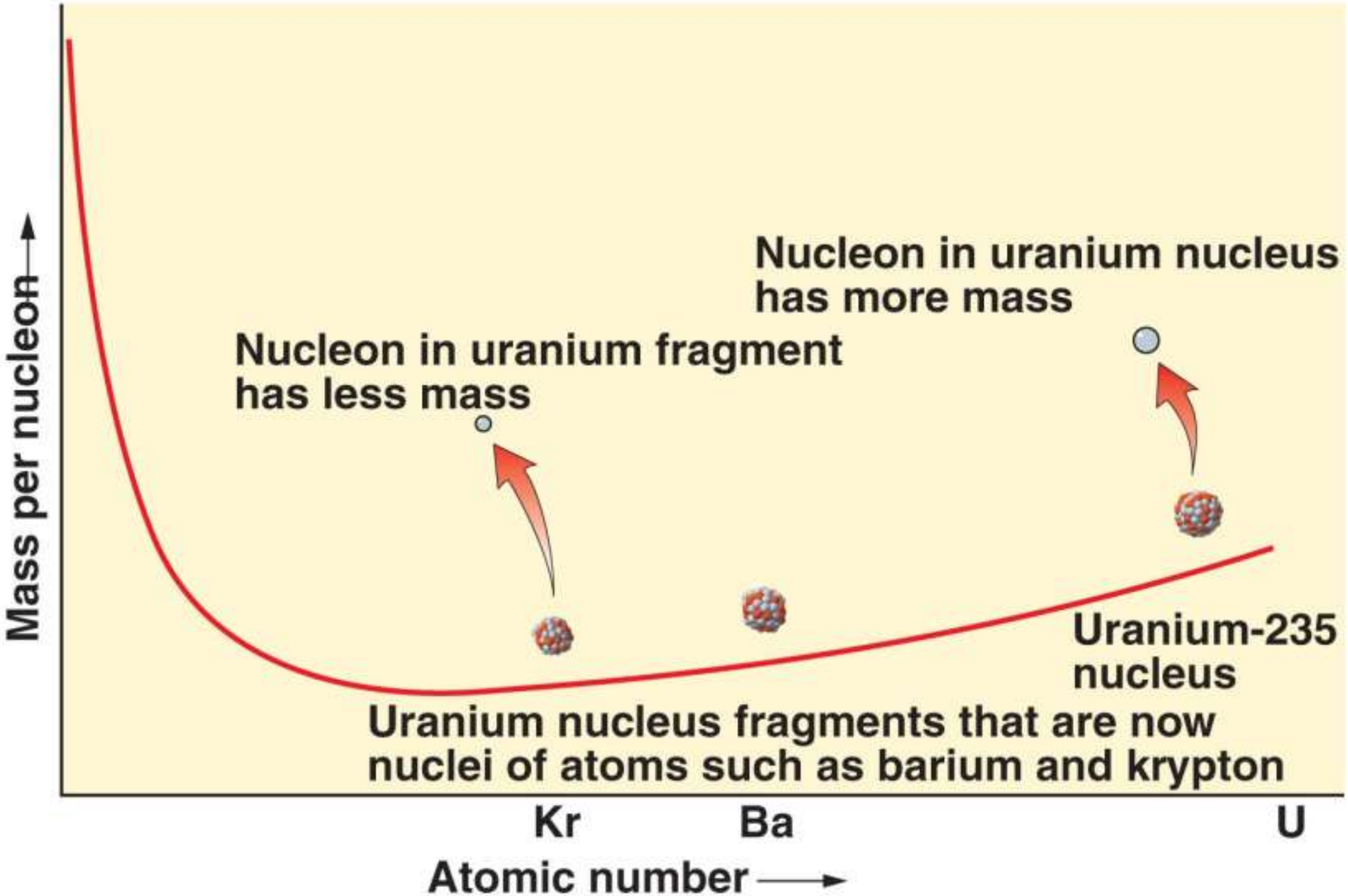
to pull its mass down.

- Iron is the most stable nucleus

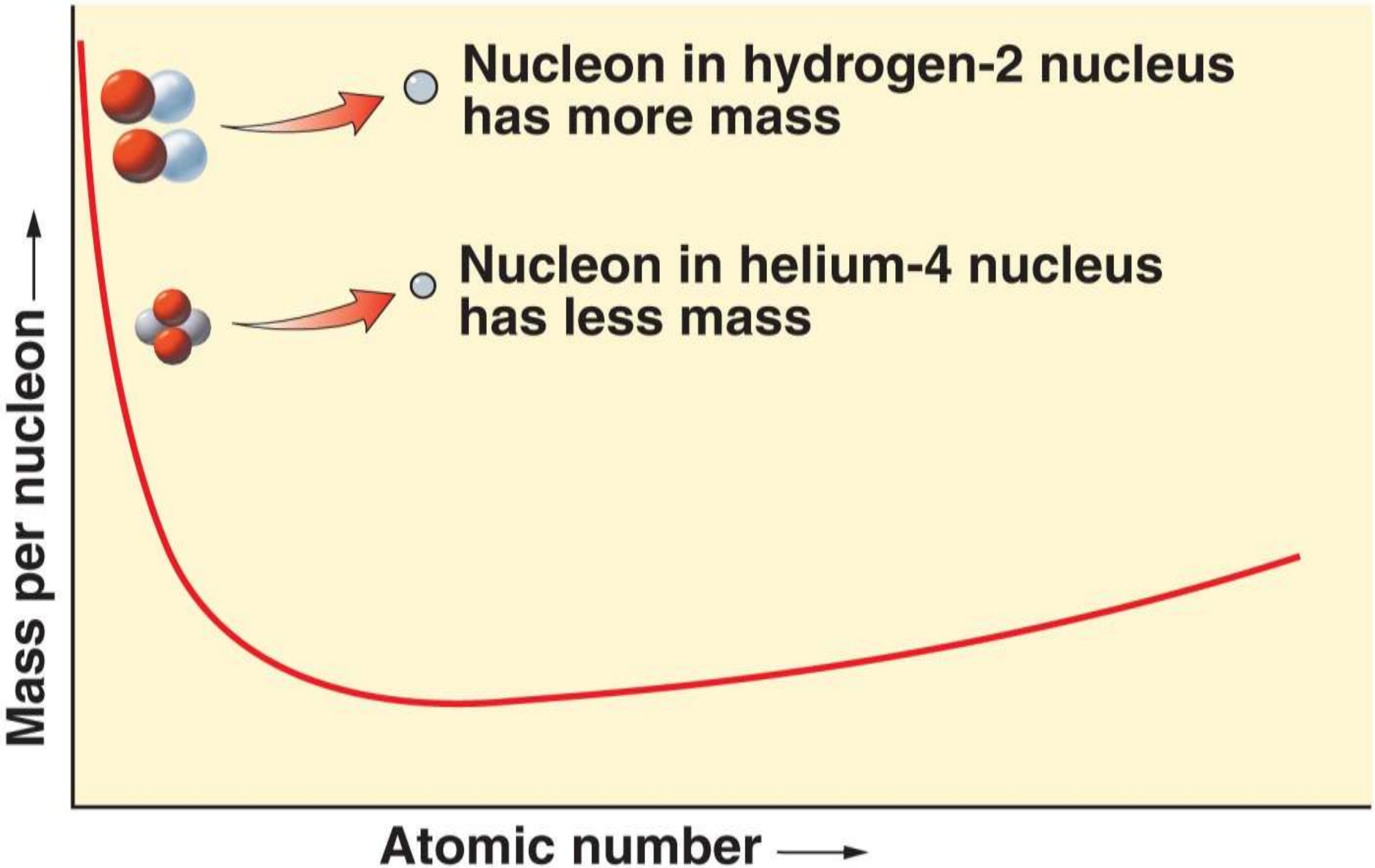
most tightly bound

most energy is needed to pull it apart

16.2 Nuclear Energy



NUCLEAR FUSION



Fusion

- What powers the Sun?
- What pulls the Sun ‘out’?
- What keeps the Sun ‘in’?
- What happens when the Sun runs out of fuel?

- fusion. fusion out, gravity in. Run out of H, all becomes He, then fuse He etc... Carbon... all run out to fuse, gravity collapses the sun, then protons repel becomes red giant, engulfs the Earth, boils away the oceans and atmosphere. bigger stars would shrink down from gravity so much until proton-proton explodes in supernova. Also heavy elements fused together get spewed out into space, from Sun to Pluto in less than 1 minute. Even more massive stars shrink into black holes.

Pop Quiz

1. [true][false] Scientists measure the amount of uranium in human remains to determine how old they are.
2. [true][false] We receive a steady supply of carbon-14 atoms from the food we eat.
3. You have 20 g of nitrogen-13 at first. Only 2.5 g are left at the end. How long did you wait?
4. List from small to big mass: alpha, beta, gamma rays
5. List from least penetrating to most penetrating: alpha beta, gamma rays.
6. Why is a half-life called a half-life?
7. Define nuclear fission
8. Define nuclear fusion
9. What is the main product of nuclear fusion on the Sun?

Pop Quiz (Open-book. No talking)

1. [true][false] Scientists measure the amount of uranium in human remains to determine how old they are.
2. [true][false] We receive a steady supply of carbon-14 atoms from the food we eat.
3. You have 20 g of nitrogen-13 at first. Only 2.5 g are left at the end. How long did you wait? 30 minutes
4. List from small to big mass: alpha> beta> gamma rays
5. List from least penetrating to most penetrating: alpha <beta< gamma rays.
6. Why is a half-life called a half-life? Time to decay to ½ original amount
7. Define nuclear fission Split large nucleus into smaller ones
8. Define nuclear fusion put smaller nuclei together to big one
9. What is the main product of nuclear fusion on the Sun? helium nucleus

Formation of a Solar System (or Galaxy)

- Nebula Theory
- Conservation of Angular Momentum $\mathbf{I}\,\omega \rightarrow \mathrm{I}\,\boldsymbol{\omega}$
- Faster pizza
- Hotter, fusion, star is born

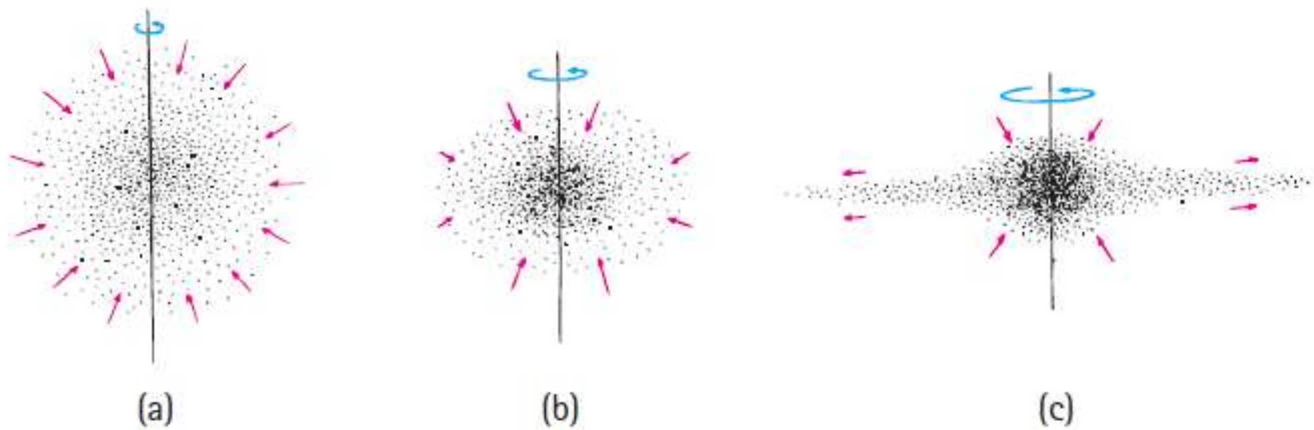


FIGURE 28.3
(a) The nebula from which the solar system formed was originally a large, diffuse cloud that rotated quite slowly. The cloud began to collapse under the influence of gravity. (b) As the cloud collapsed, it heated up as gravitational potential energy converted to heat. It spun faster by the conservation of angular momentum. (c) The cloud flattened into a disk as a result of its fast rotation. A spinning, flattened disk was produced whose mass was concentrated at its hot center.

Ch. 33 Our Universe

- 91% of atoms in the universe is hydrogen
- There's more matter than antimatter
- There's more dark matter than matter
- There's more dark energy than dark matter

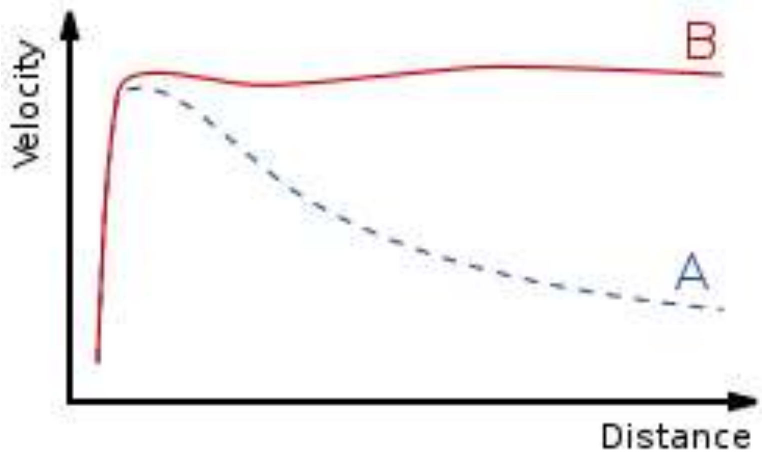
96% of the universe is made of something
we can't see
or detect (yet)…

Does your Rotation Curve match?

- Fritz Zwicky
- Vera Rubin

- What is the significance?

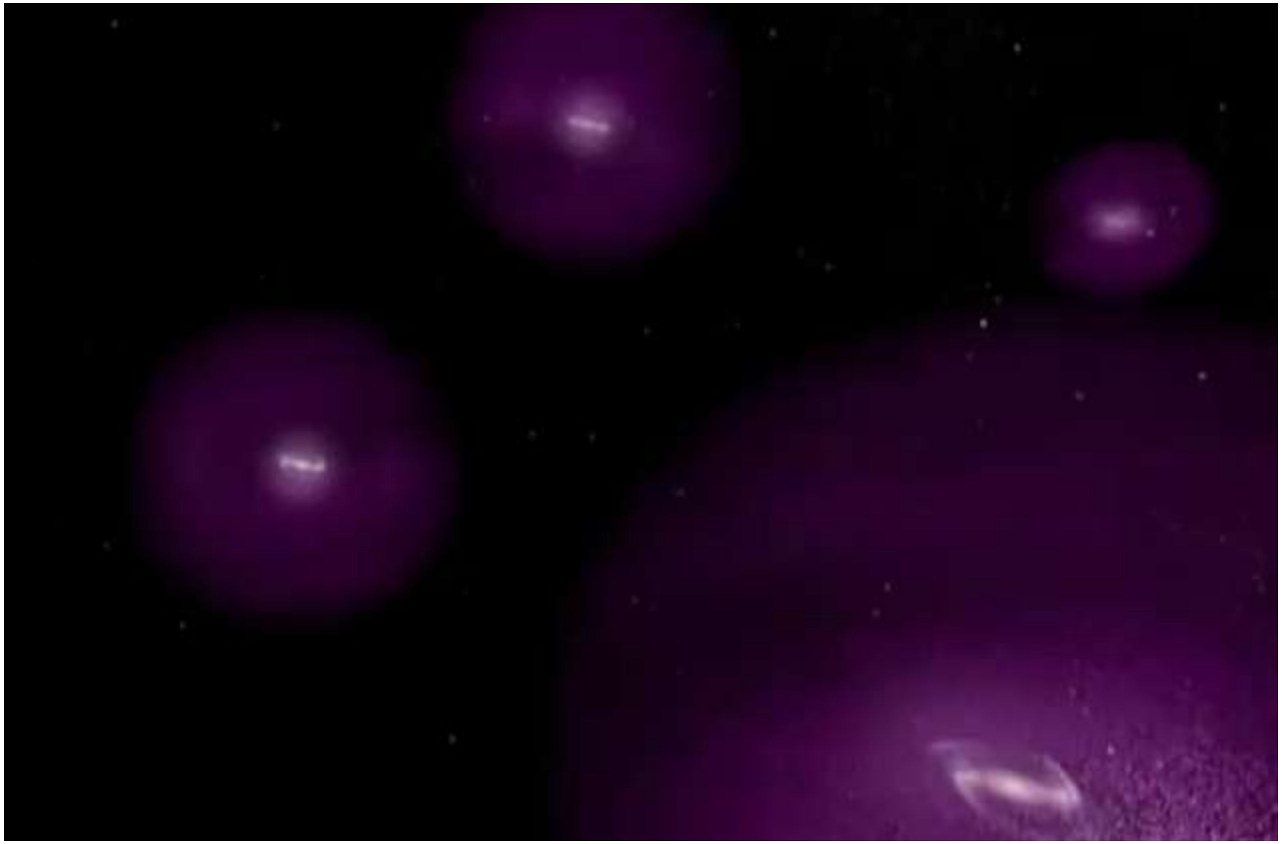
SIGNIFICANCE?



1. The Laws of Physics are incorrect

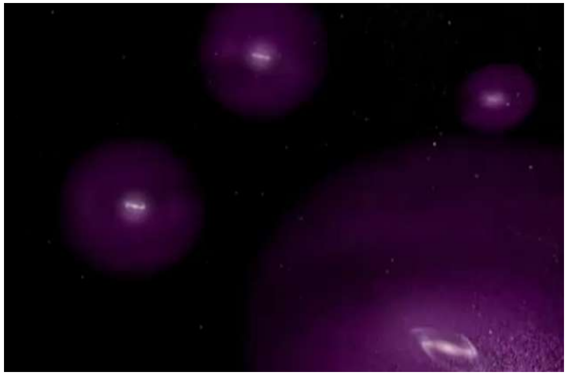
2. Some new kind of mass is out there

Galaxies in Dark Matter globs



Another Question

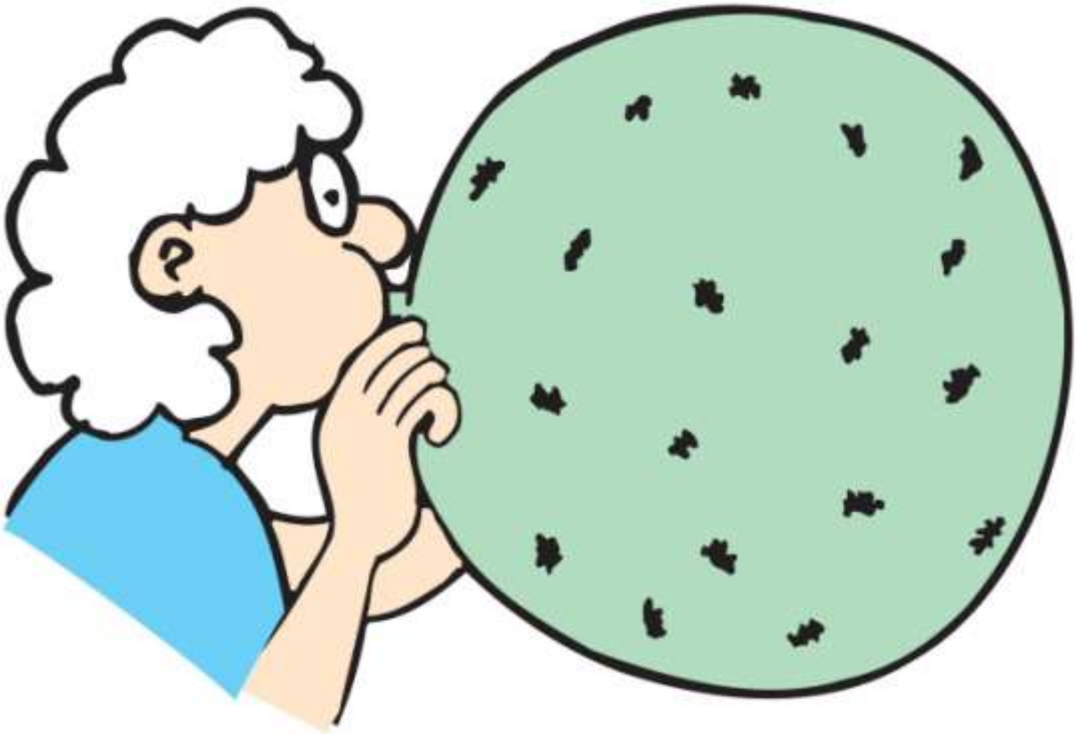
- Estimate the dark matter from globs around galaxies.



- Still not enough mass!
  - 4% ordinary matter
  - 96% dark stuff → only found 21%

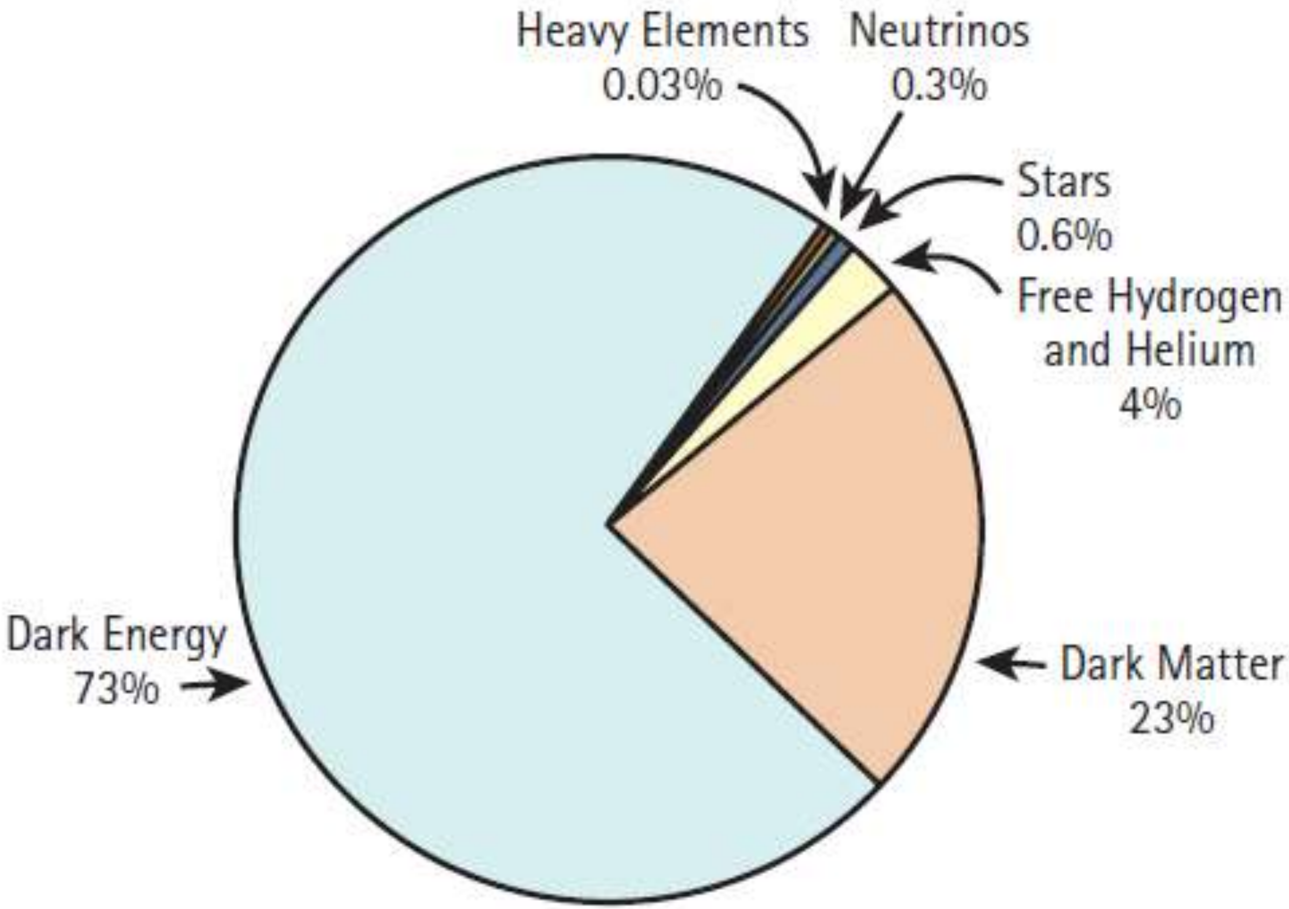
Yet Another Question

YET ANOTHER QUESTION



- A mysterious energy

The Standard Model of the Universe



Fate of the Universe

- Big Bang
- No Big Crunch? → Dark Energy

- Heat Death (Max Entropy)
- Big Rip

SETI

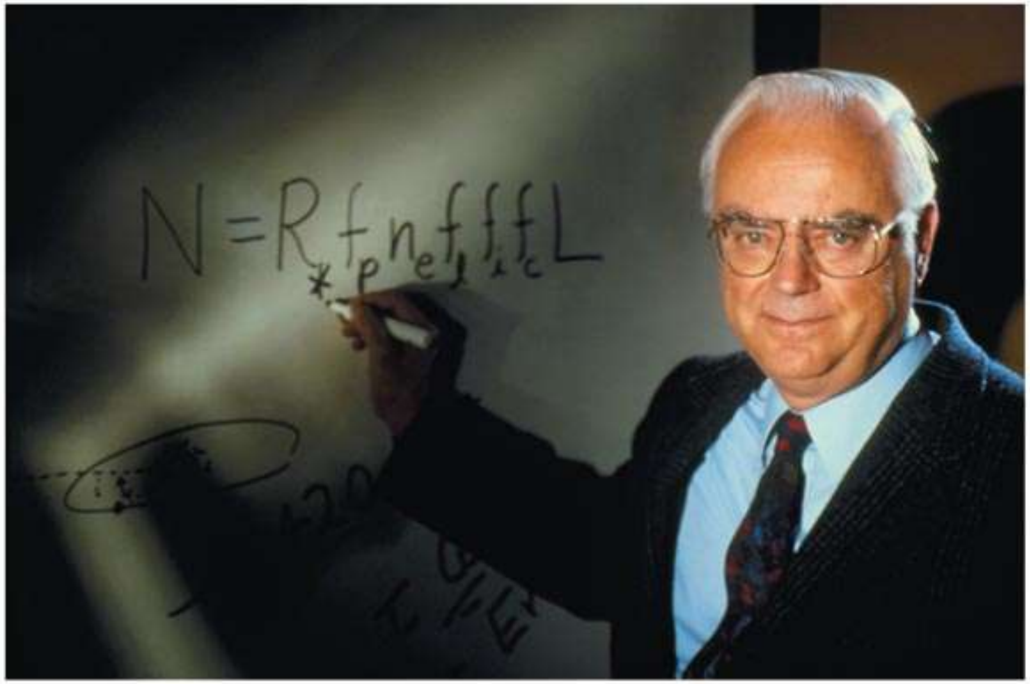
- 1959
- Radio waves leaking into space
- 100 billion planets in the Milky Way could support life

- 3.5 billion years for humans to develop
  - Modern humans 195,000 years ago
  - Art, music… 50,000 years ago
  - Radio waves… < 100 years
  - Other side of our galaxy: 100,000 years

- Timing problem

The Drake Equation: What are the odds of contact in our Galaxy?

- Rate of star formation in our galaxy
- Fraction of stars with planets
- Number of planets that can support life
- Fraction of those planets that actually develop life
- Fraction of above with intelligent life
- Fraction of civilizations with technology that release signals to space
- Length of time signals have been released into space



N = the number of civilizations in our galaxy with which communication might be possible = 0.000065 ~ 20,000 (closest 350 light years away)

Anthropic Principle

- "If the universe were even a little different than it is, we could not be here. A poet might say that the universe is exquisitely tuned, almost as if to accommodate us."

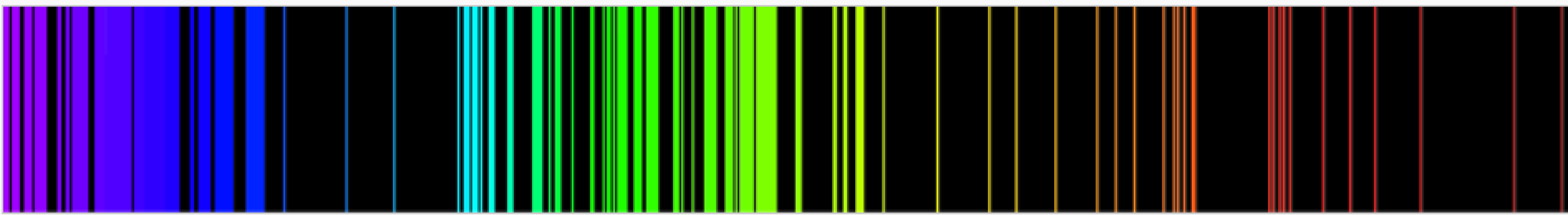
Modern Atomic Theory

EMISSION SPECTRUM

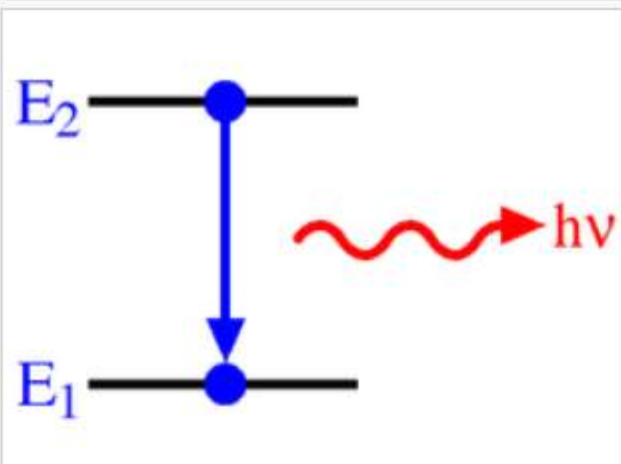
- Light as photons: packets of energy
- Which color's photons has higher energy? Red or purple?

Emission Spectrum: energy levels are quantized

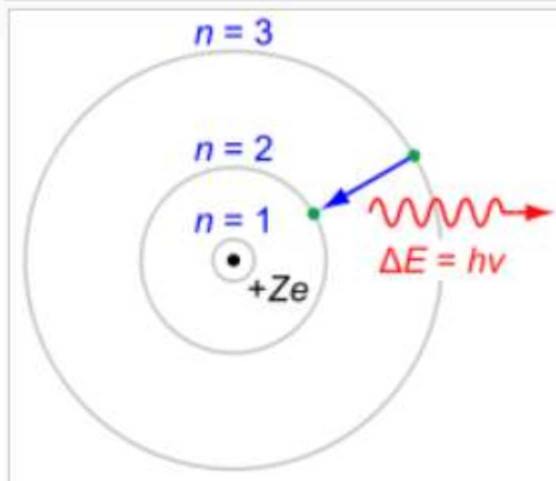
Emission spectrum of Hydrogen



Emission sp



Schematic diagram of spontaneous emission



The Rutherford–Bohr model of the hydrogen atom.

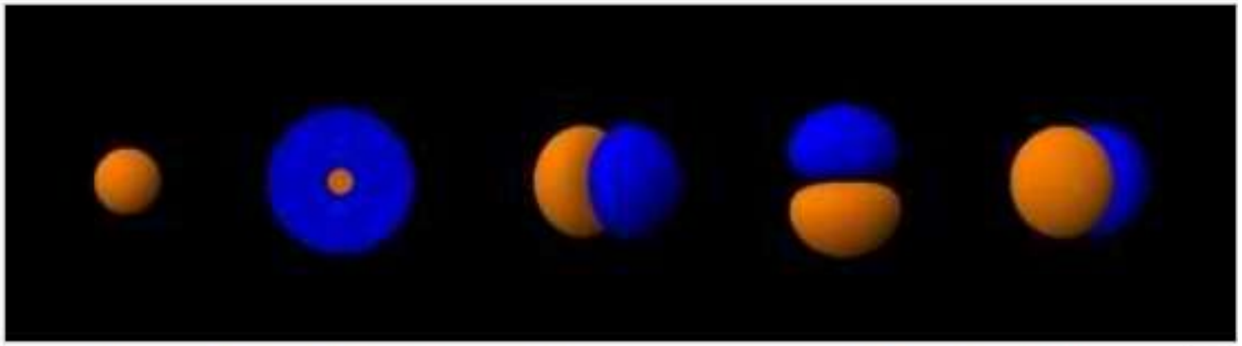
- Wikipedia
- Emission spectrum
- Atomic orbital

Bohr Model

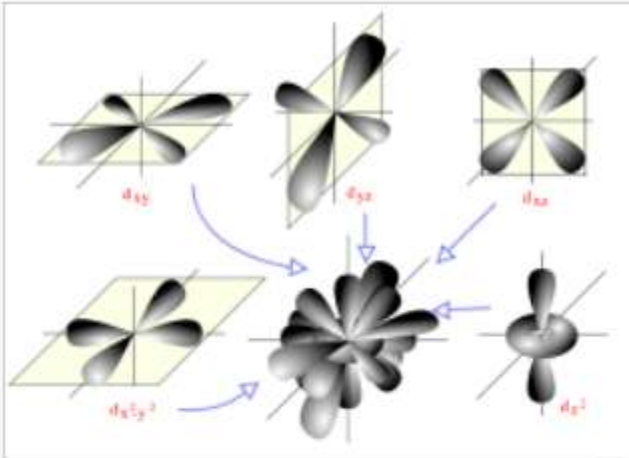
- Discrete energy levels, like orbits/ ladder

WAVE MECHANICAL MODEL OF THE ATOM

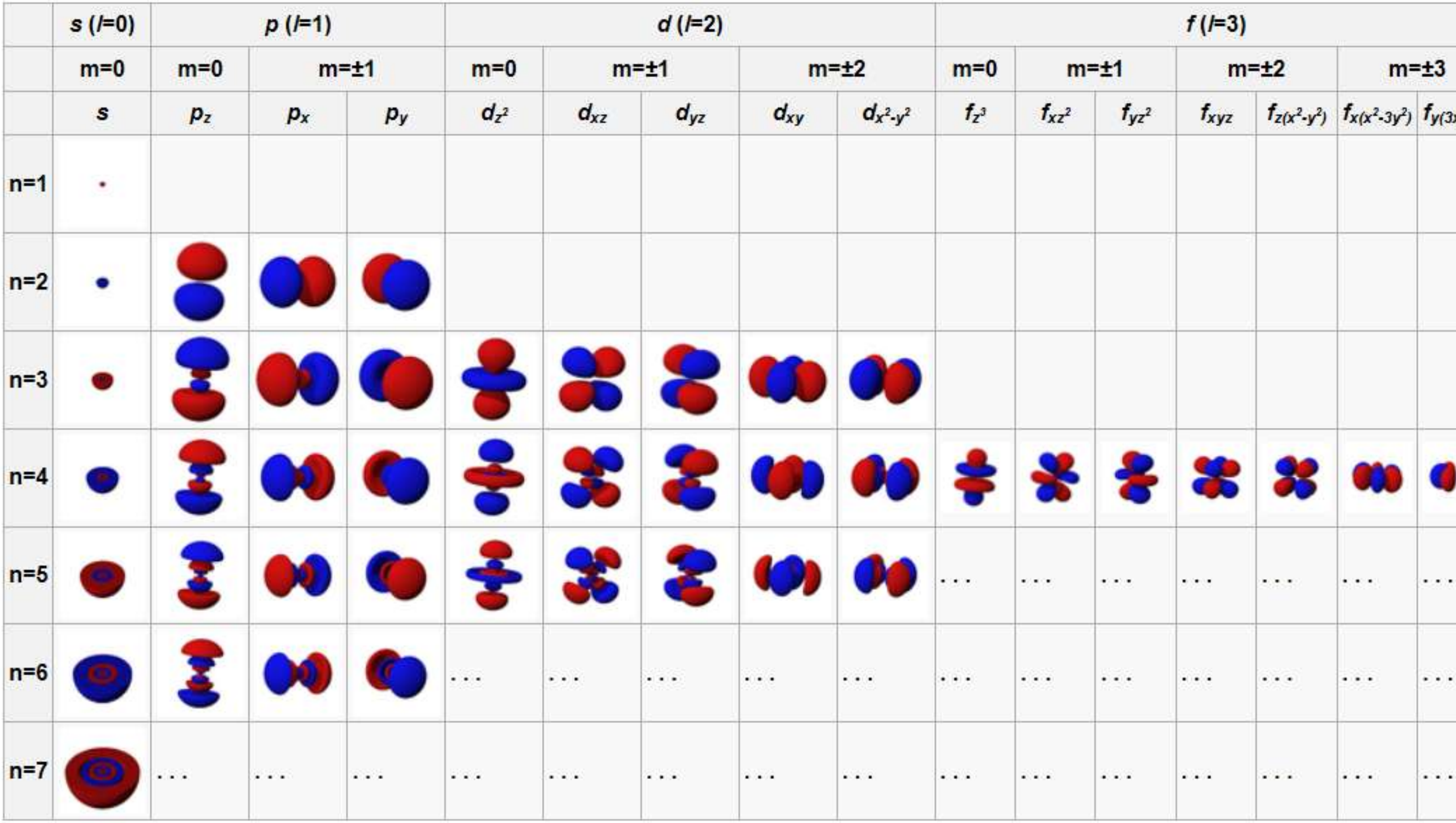
- Electron cloud: orbital = probability map
- The electron is 90% likely to be *anywhere* in the cloud.

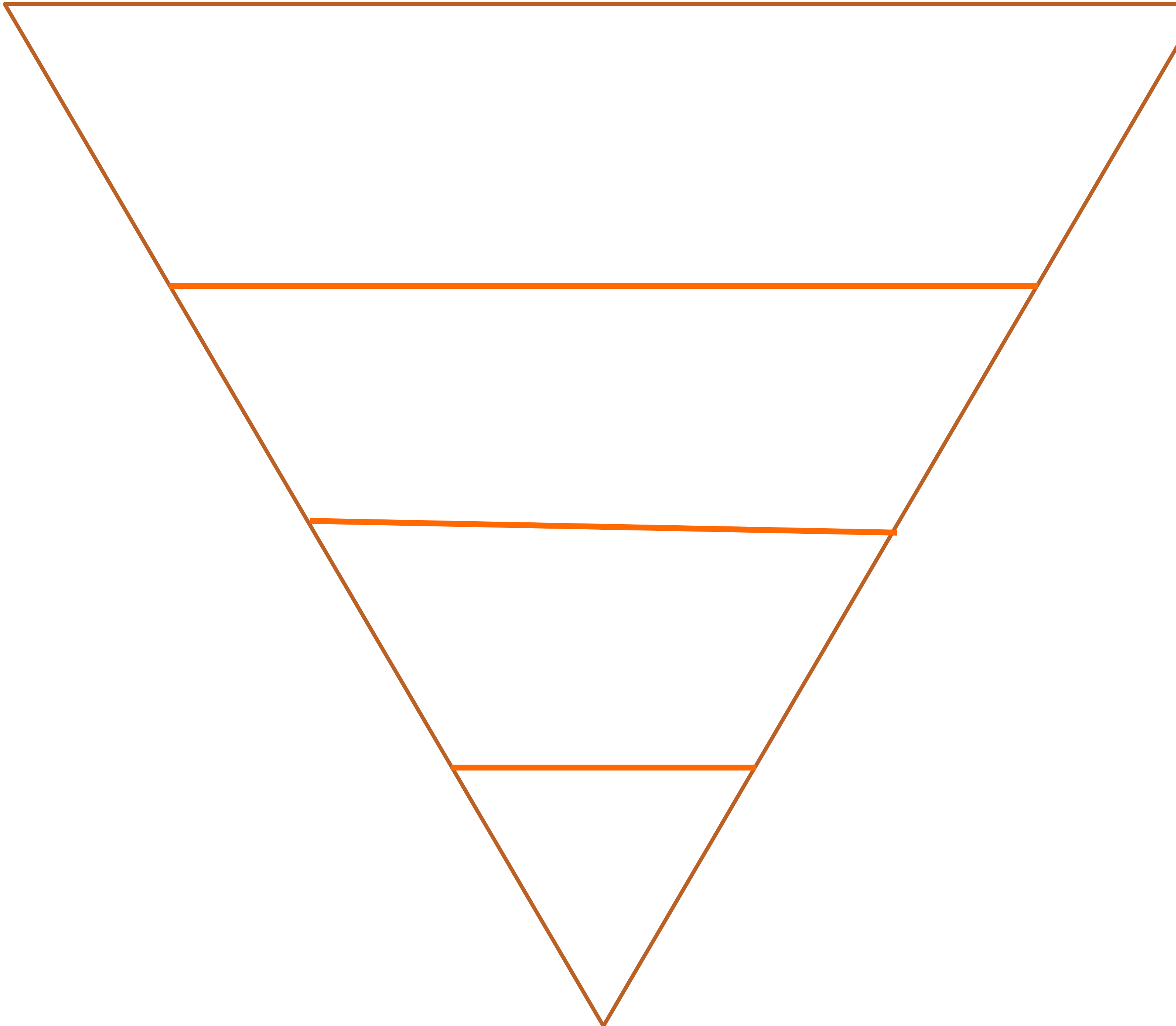


The shapes of the first five atomic orbitals: 1s, 2s, $2p_x$, $2p_y$, and $2p_z$. The colors show the wave function phase. These are graphs of $\psi(x,y,z)$ functions which depend on the coordinates of one electron. To see the elongated shape of $\psi(x,y,z)^2$ functions that show probability density more directly, see the graphs of d-orbitals below.



The five d orbitals in $\psi(x,y,z)^2$ form, with a combination diagram showing how they fit together to fill space around an atomic nucleus.


s (l=0)
p (l=1)
d (l=2)
f (l=3)
m=0
m=±1
m=±2
m=±3
s
p_z
p_x
p_y
d_z²
d_xz
d_yz
d_xy
d_x²-y²
f_z³
f_xz²
f_yz²
f_xyz
f_z(x²-y²)
f_x(x²-3y²)
n=1
n=2
n=3
n=4
n=5
n=6
n=7



eory

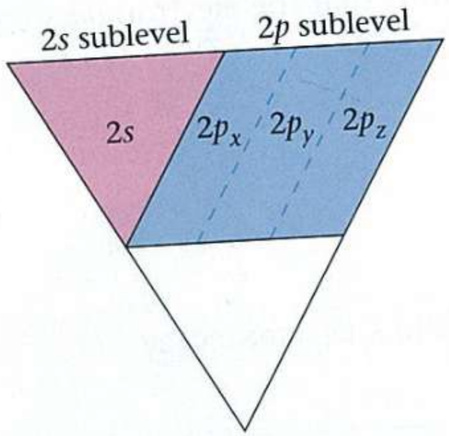


Figure 11.23
Principal level 2 shown divided into the 2*s* and 2*p* sublevels.

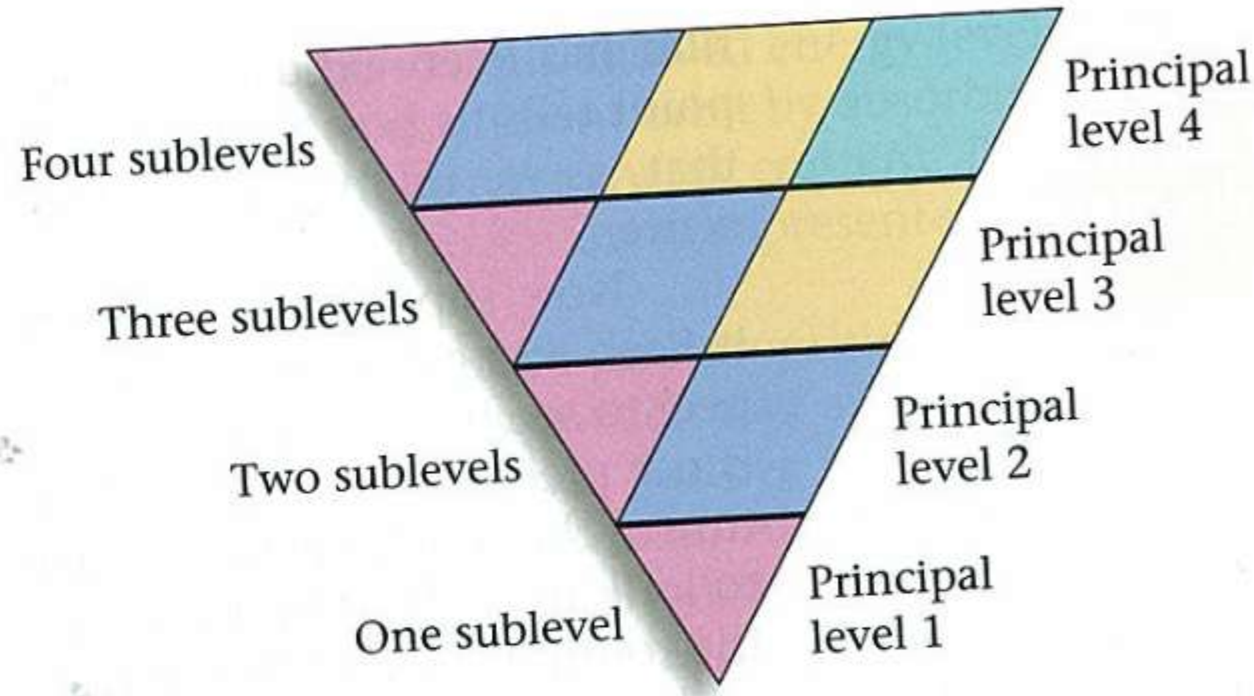
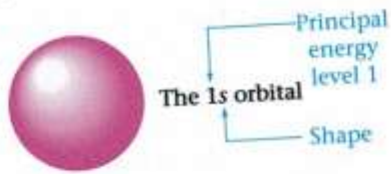


Figure 11.22
An illustration of how principal levels can be divided into sublevels.

Figure 11.24
The relative sizes of the 1*s* and 2*s* orbitals of hydrogen.



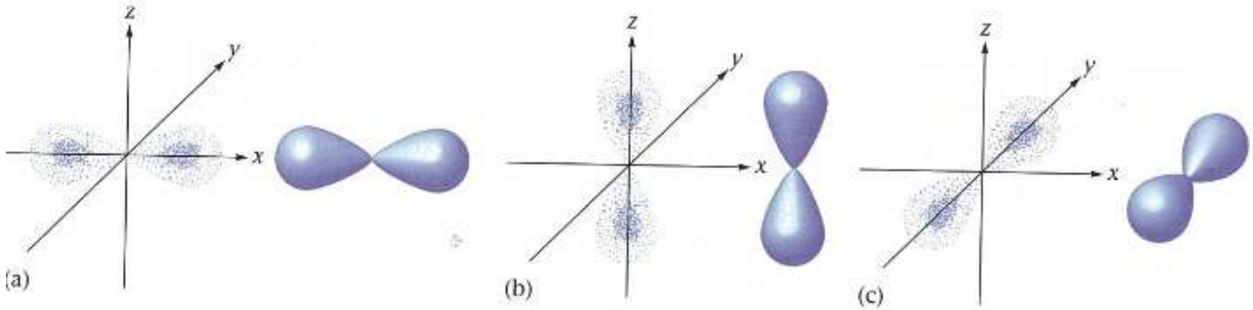


Figure 11.25
The three $2p$ orbitals: (a) $2p_x$, (b) $2p_z$, (c) $2p_y$. The x, y, or z label indicates along which axis the two lobes are directed. Each orbital is shown both as a probability map and as a surface that encloses 90% of the electron probability.

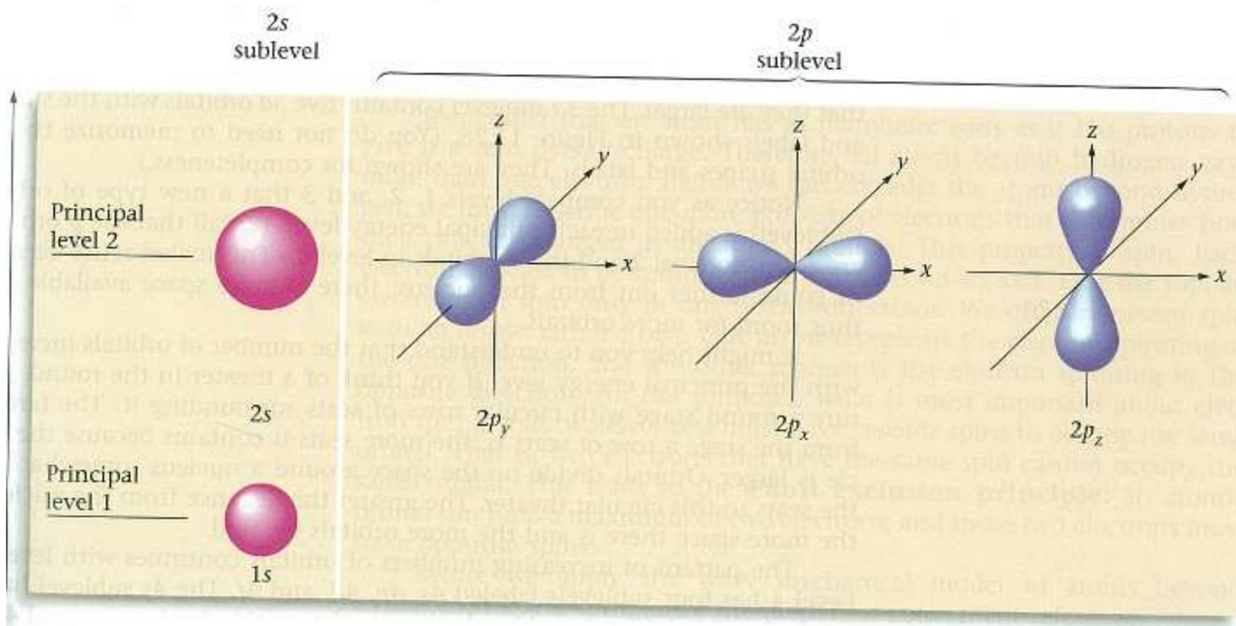
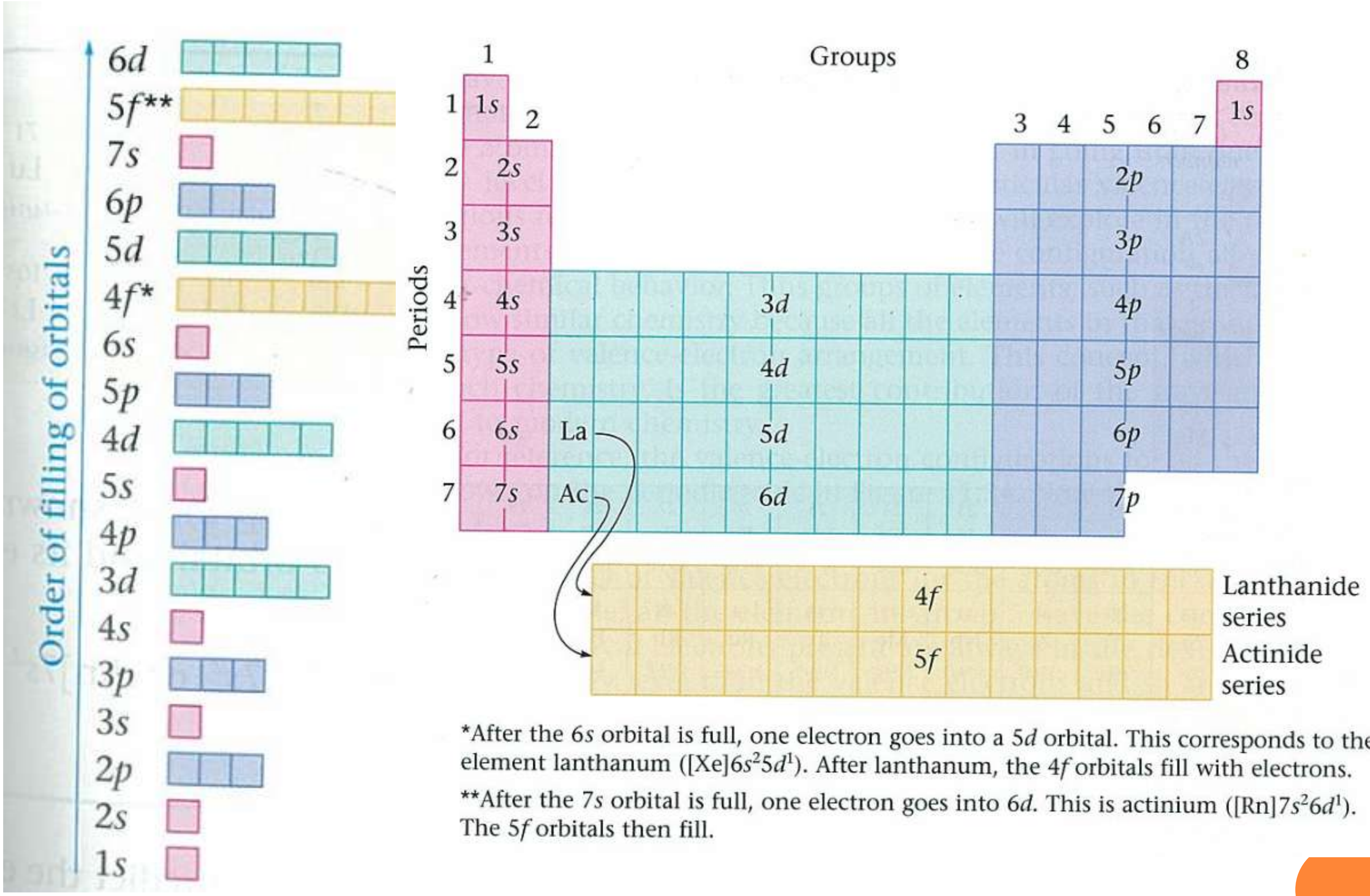


Figure 11.26
A diagram of principal energy levels 1 and 2 showing the shapes of orbitals that compose the sublevels.

Electron configuration and Orbital Diagram

- Pauli exclusion principle: An orbital can hold at most 2 electrons, with opposite spins.
- Start filling in the orbitals in this order:

  1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p, 6s, 4f, 5d, 6p, 7s, 5f, 6d, 7p, (8s, 5g, 6f, 7d, 8p, and 9s)
- n = 1, 2, 3, … is the principle quantum number, the "shell" in our book's model.
- Valence electrons are the s and d electrons in the nth shell.
- We won't consider the transition metals. (1~2 valence electrons)
- See next slide



*After the 6*s* orbital is full, one electron goes into a 5*d* orbital. This corresponds to the element lanthanum ([Xe]$6s^2 5d^1$). After lanthanum, the 4*f* orbitals fill with electrons.

**After the 7*s* orbital is full, one electron goes into 6*d*. This is actinium ([Rn]$7s^2 6d^1$). The 5*f* orbitals then fill.

EXAMPLES

- Electron configuration, orbital diagram, and our shell model

Year	Cost/pound (0.5 kg)
1855	$100,000/lb.
After electrolysis	
1885	100
1890	2
1895	0.5
1970	0.3
1980	0.8
1990	0.74

Aluminum

Chem sidenote