Making Sense of the Universe (Chapter 4)

Momentum, Energy, and Matter

Part of Chapter 4, plus section 3 of Chapter 5

Based on parts of Chapters 4 and 5

- This material will be useful for understanding Chapters 5, 8, 9, 10, and 14 on “Light”, “Formation of the solar system”, “Planetary Geology”, “Planetary Atmospheres” and “Jovian planet systems”
- Chapter 3 on “Years, seasons, and months” will be useful for understanding this chapter

Goals for Learning

- What are momentum, angular momentum, and energy?
- How can they change?
- What are atoms made of?
- How do atoms affect larger objects?
- How can atoms store energy?

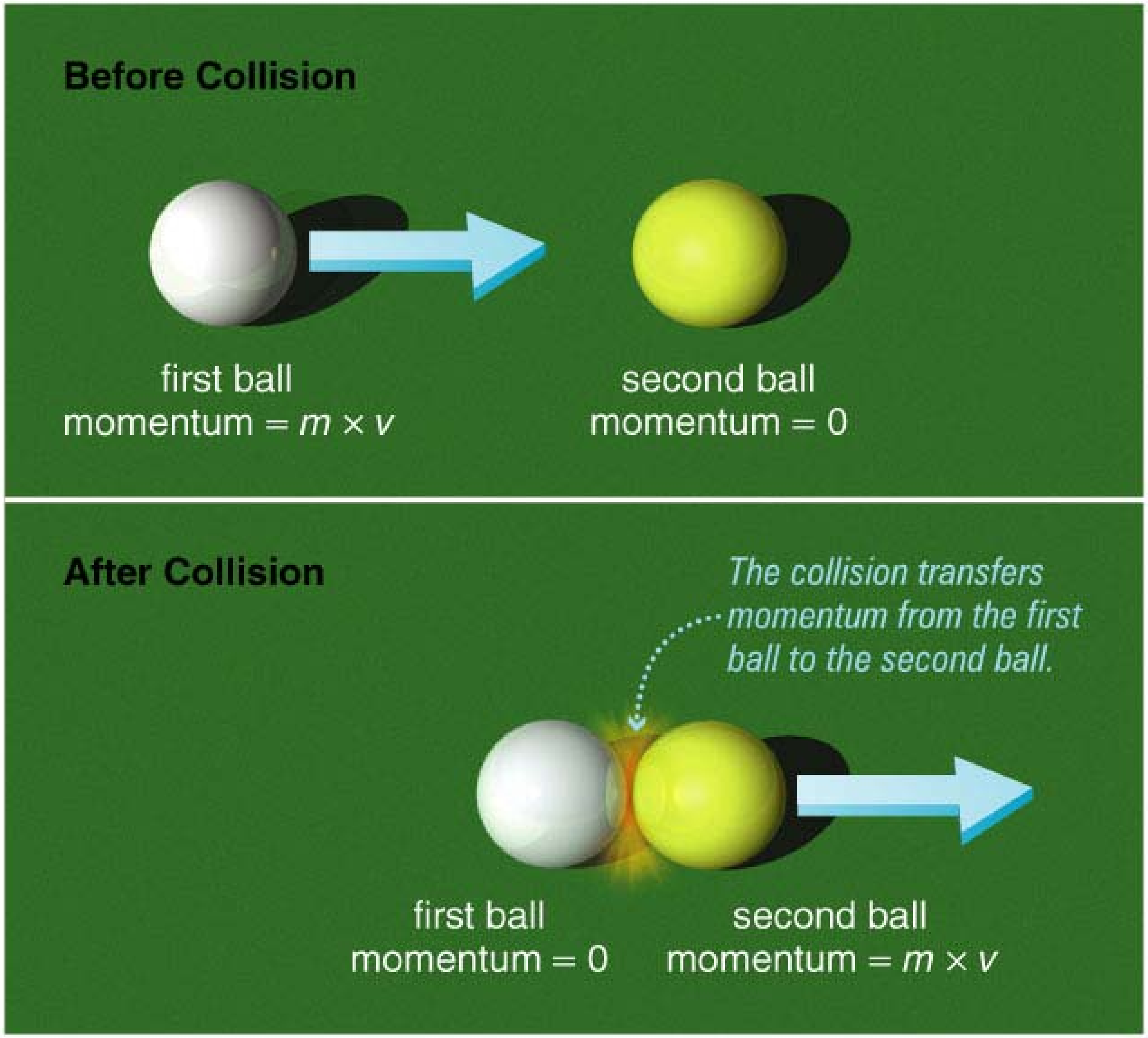
Newton's Laws

- Velocity is constant without a net force
- F=ma
- Every force has an equal and opposite force

- These are consistent with one principle – the principle of conservation of momentum

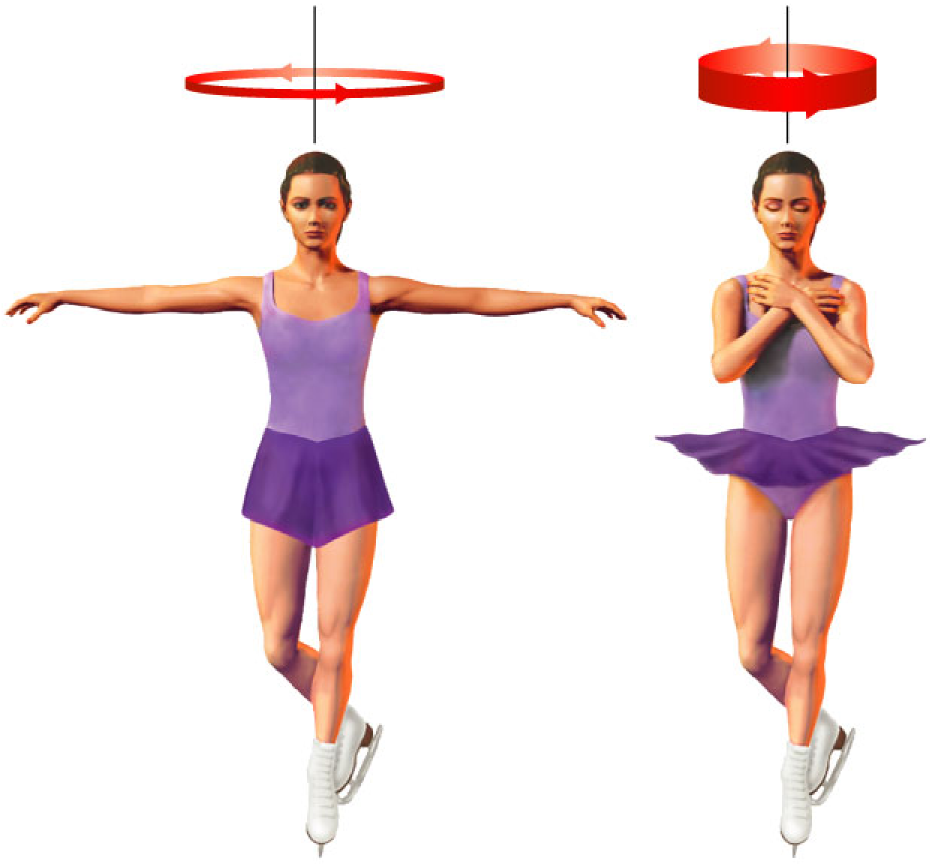
Momentum

- Momentum = mass x velocity
- The total momentum of interacting objects stays the same if no external forces are acting on them


Before Collision
first ball
momentum = m × v
second ball
momentum = 0
After Collision
The collision transfers momentum from the first ball to the second ball.
first ball
momentum = 0
second ball
momentum = m × v

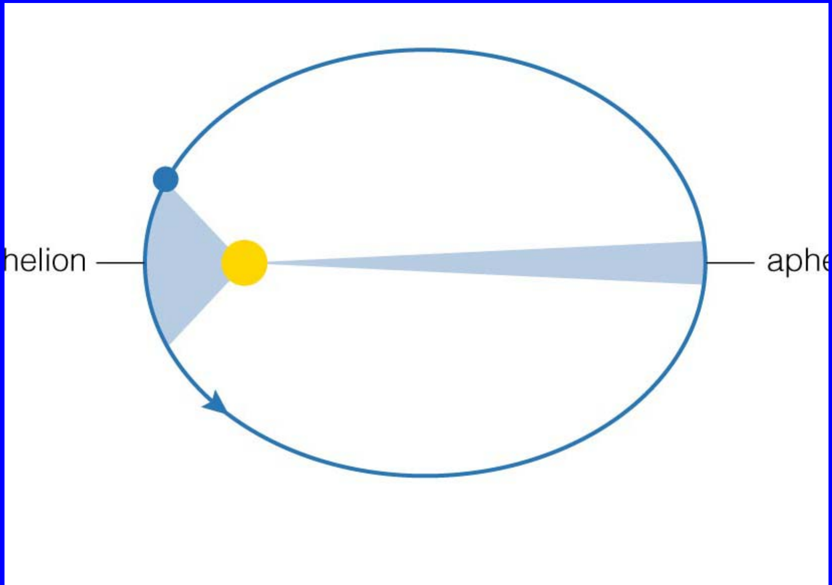
Angular Momentum

- Parts of the skater are moving, although the skater has no overall velocity
- Does the skater have any momentum?



Two types of Angular Momentum

- Orbital angular momentum
  = m x v x r



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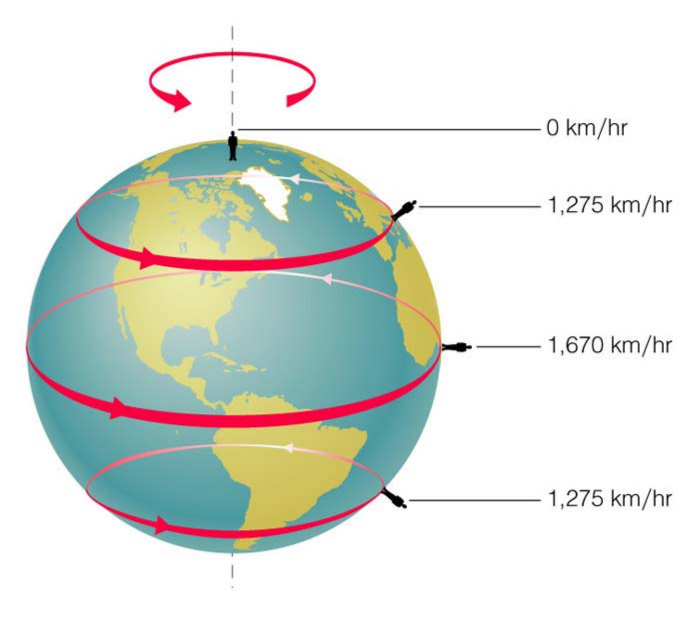
- Rotational angular momentum



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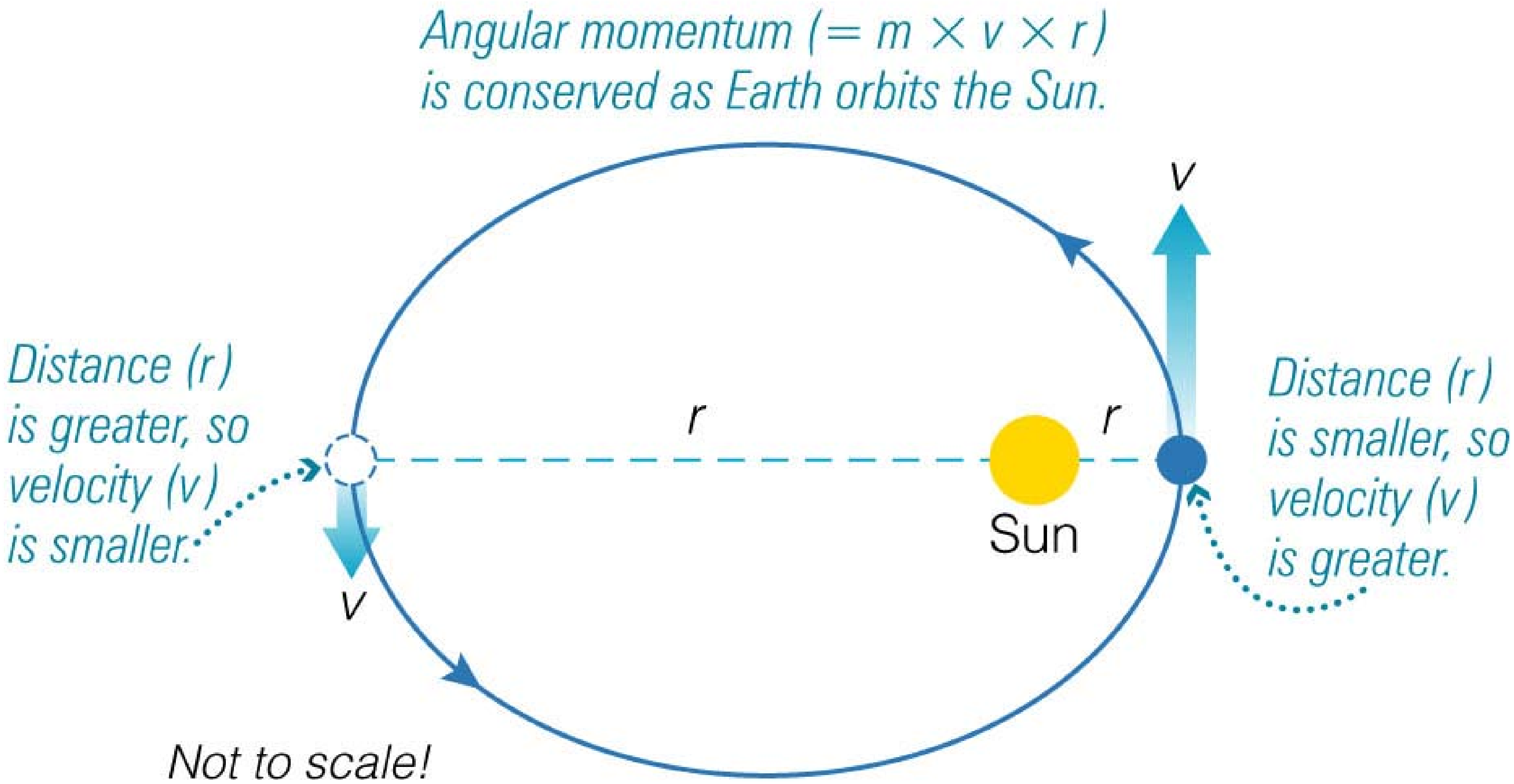
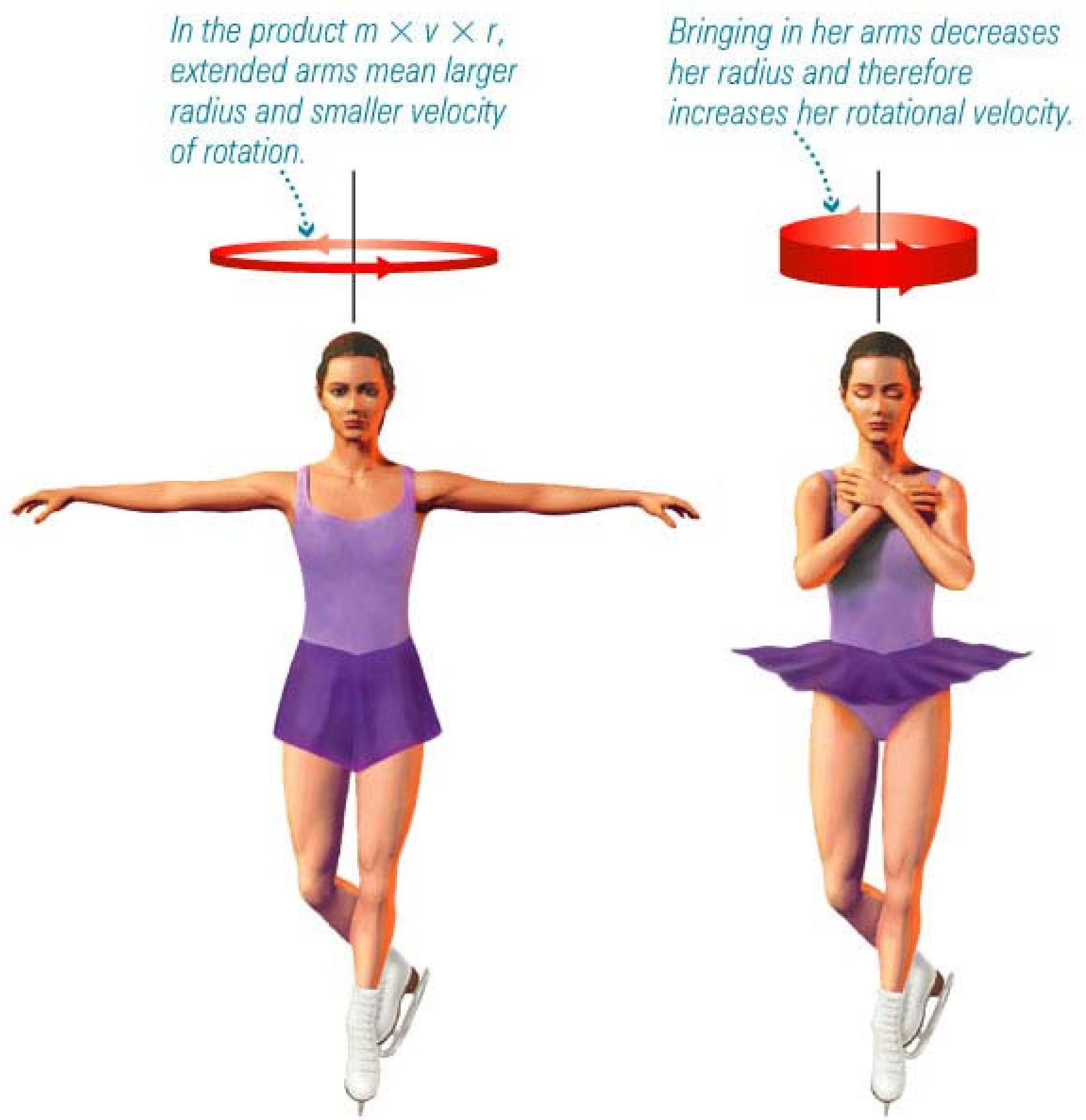
Conservation of Angular Momentum

- The angular momentum of a set of interacting objects can only be altered by an external torque
- A “torque” is a “twisting force”
- Torque is to angular momentum what force is to momentum



Kepler's Second Law is a consequence
of the conservation of angular momentum



- Angular momentum will be important for understanding how the solar system formed

- The planets must keep orbiting the Sun again and again because there is no way for them to change their orbital angular momentum
- The planets must keep rotating around their axes because there is no way for them to change their rotational angular momentum
- What is the difference between orbital and rotational angular momentum?

Energy

- Energy is what makes matter move
- Energy cannot be created or destroyed, only exchanged or transferred – the third big conservation principle
- Just about every process in the universe can be understood based upon the conservation of momentum, angular momentum, and energy

Categories of Energy

- Kinetic Energy – the energy of motion
- Radiative Energy – the energy carried by light. Radiation is often used to mean light, and things similar to light. It doesn’t suggest anything nuclear
- Potential Energy – stored energy that might later be converted into kinetic or potential energy

What type of energy?

- A runner
- A falling rock
- A rock about to fall from a high cliff
- A chocolate bar
- A can of gasoline
- A battery
- A beam of light
- An X-ray

Units of Energy

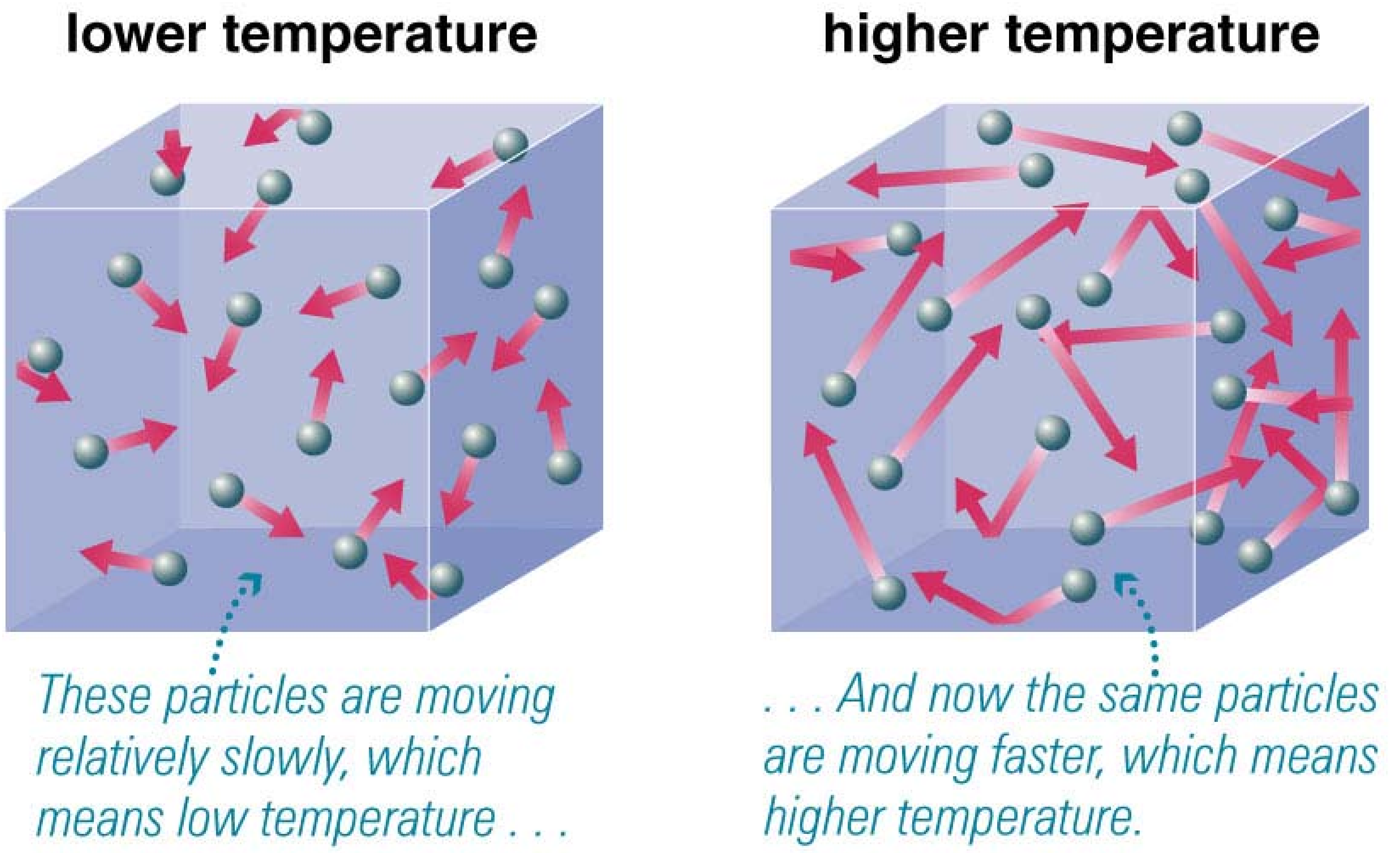
- 1 food Calorie = 4184 Joules
- A typical adult needs 2500 food Calories per day
- Scientists usually work in Joules

Kinetic Energy

- The kinetic energy of an object depends on its mass and its velocity
- The greater the mass and the greater the velocity, the greater the kinetic energy
- Large things (cars, people) have kinetic energy when they move
- Small things (molecules in cars, people, rock, or air) also move and have kinetic energy

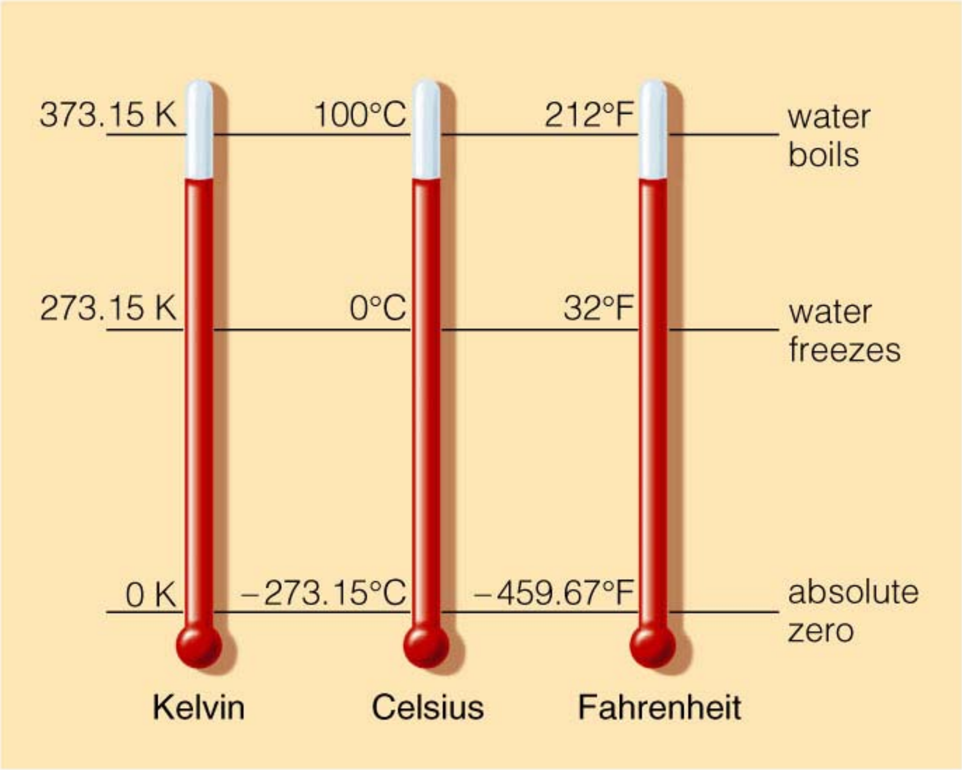
Thermal Energy

- Molecules are always moving
- Thermal energy of an object is the total kinetic energy of all the randomly moving molecules in the object
- Temperature of that object is a measure of the average kinetic energy of each molecule


lower temperature
higher temperature
These particles are moving relatively slowly, which means low temperature . . .
. . . And now the same particles are moving faster, which means higher temperature.

Temperature

- Higher temperature means that the molecules within the object are moving faster
- Fahrenheit
- Celsius
- Kelvin



Difference between thermal energy and temperature

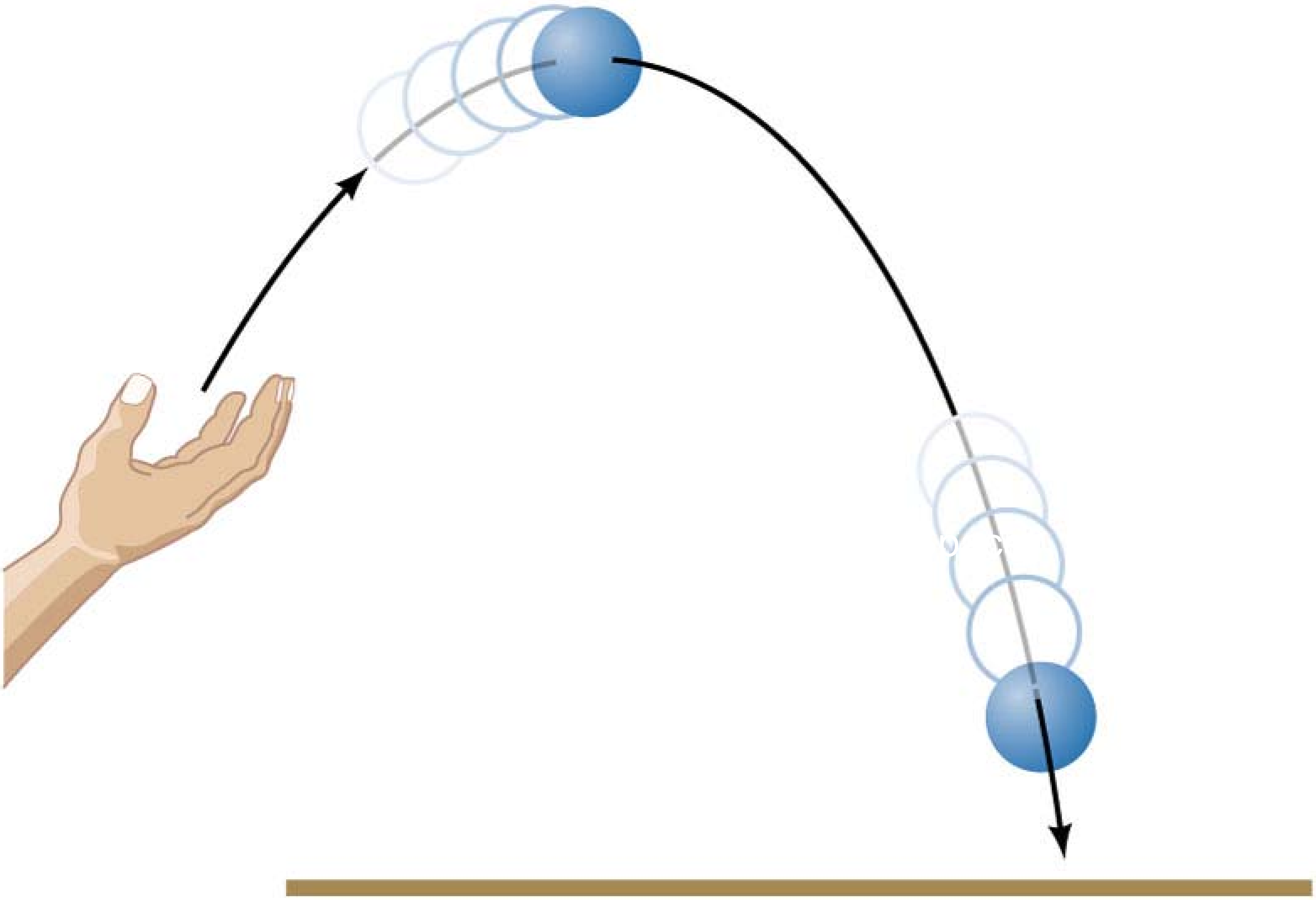
- 400F oven and 212F boiling water
- Which would you rather put your hand into?
- Which contains more thermal energy?
- Which has a higher temperature?

Radiative Energy

- Wait until we learn more about light in the next class

Potential Energy

- Gravitational Potential Energy – The energy that would be converted into kinetic energy if the object fell downwards
- The greater the mass of an object, and the higher up it is, the more gravitational potential energy the object has got



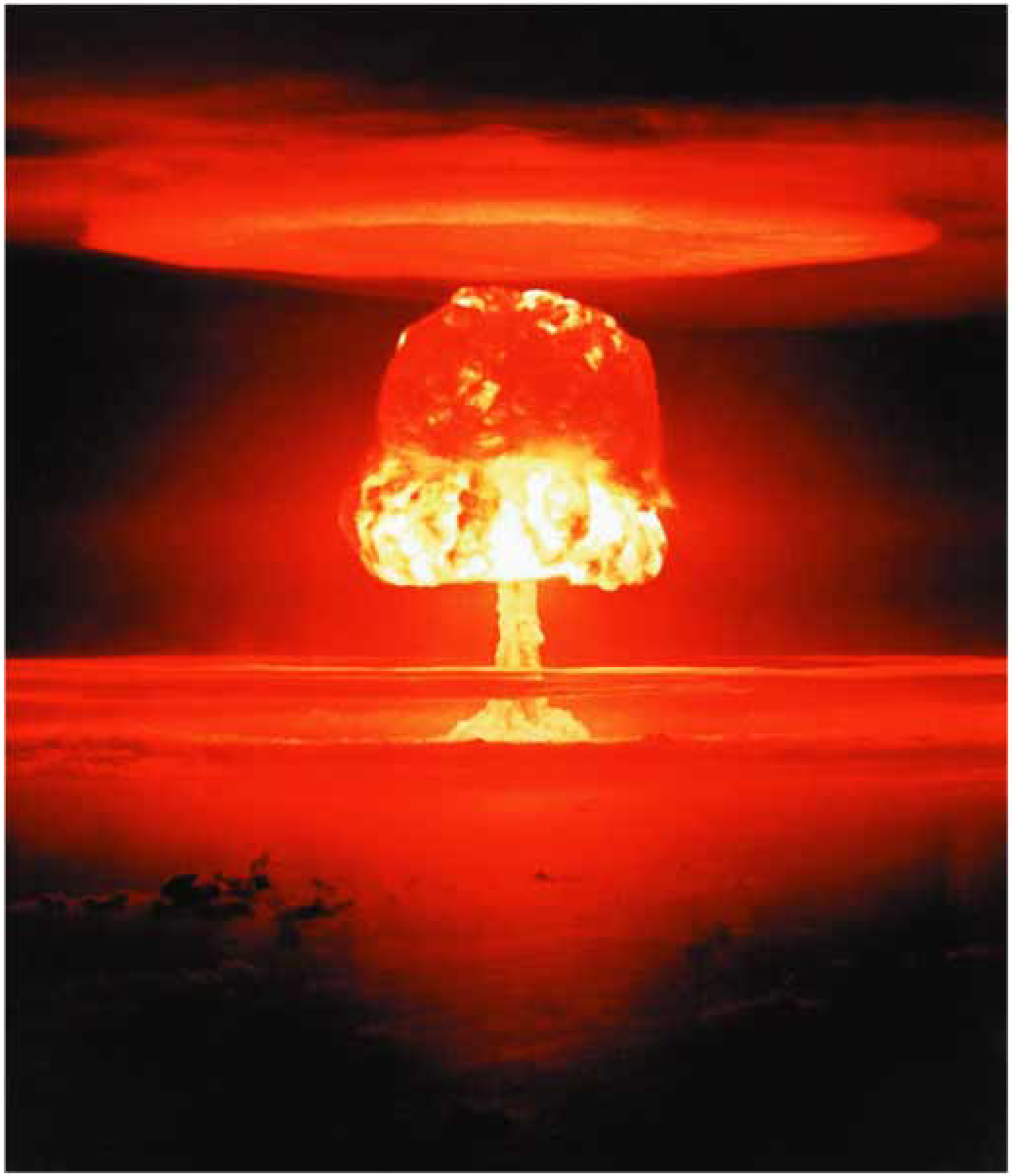
Interactive Figure - Energy of a Cannonball Fired into Space

Escape Velocity

- Suppose Earth were the only thing in the Universe. If we dropped something from the edge of the Universe, it would fall towards Earth, constantly accelerating, until it hit Earth's surface at 11 km/s
- What happens if we shoot something upwards at 1 km/s, 11 km/s, 12 km/s?

Potential Energy

- Mass-energy – $E=mc^2$
- Mass can be converted into energy and energy can be converted into mass
- It is difficult to convert mass into energy
- A small mass contains a lot of energy
- Very important for stars, not very important for planets



A hydrogen bomb

Energy = 1-megaton

Same energy as
1 million tonnes of
typical explosive

This bomb converted
100 g of mass into
energy

Properties of Matter

- Everything consists of protons, neutrons, and electrons
- The way protons, neutrons, and electrons are joined together within an object controls the properties of the object
  - density
  - solid/liquid/gas
  - colour
  - flammable
  - radioactive

Protons, Neutrons, and Electrons

- Proton – 1.67×10^{-27} kg, charge = +1
- Neutron – 1.67×10^{-27} kg, charge = 0
- Electron – 9.1×10^{-31} kg, charge = -1

- 1800 electrons weigh as much as 1 proton
- Proton and neutron radius = 10^{-15} m
- Electron radius = ???

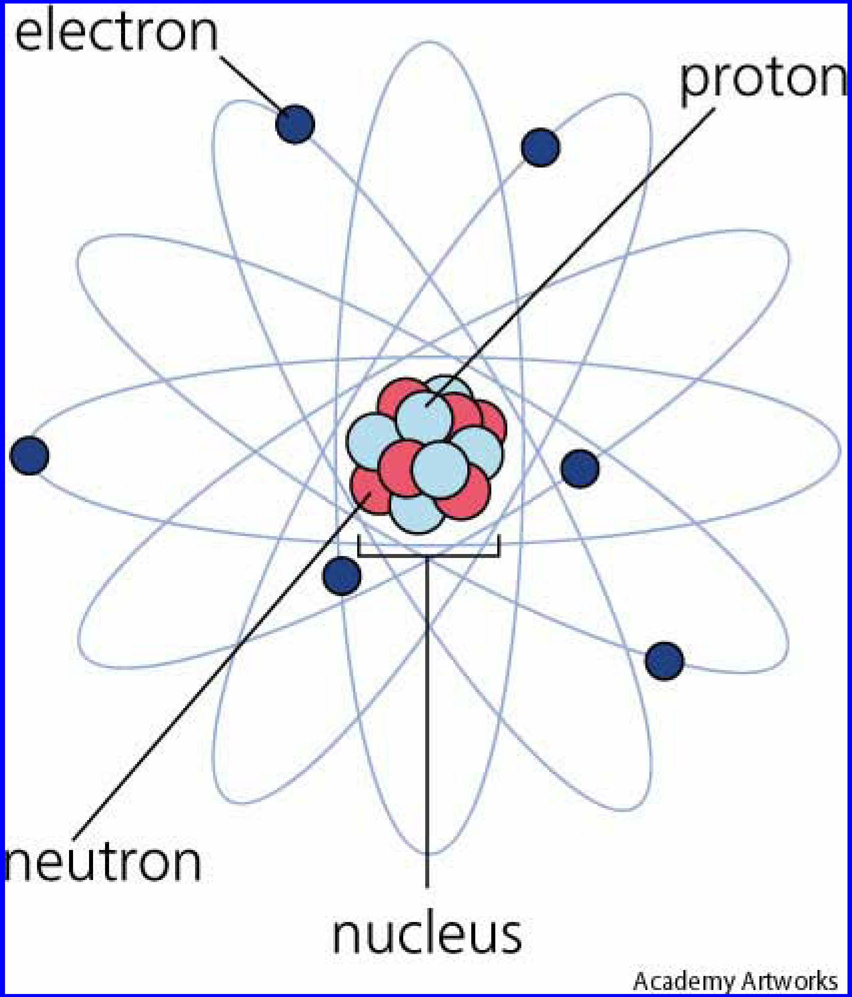
Electric (Electromagnetic) Forces

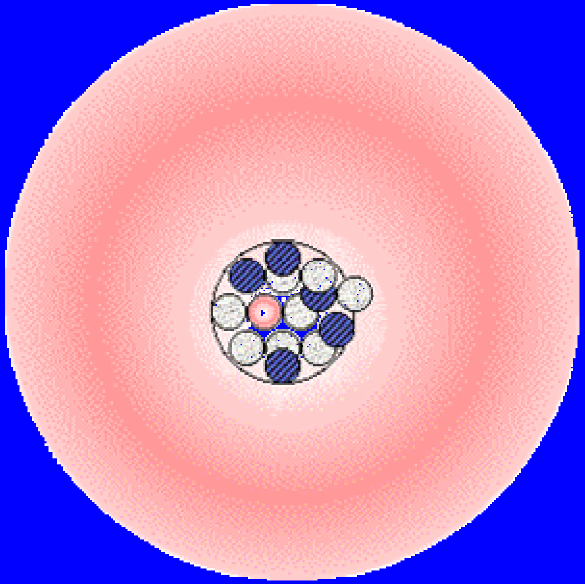
- Gravity controls the behaviour of big things like planets (lots of mass, electrically neutral)
- Electric forces control the behaviour of small things like electrons (tiny mass, but not neutral)

- Two particles with the same charge repel each other (++, --)
- Two particles with the opposite charge (+-, -+) attract each other

Atoms

- Matter is made up of atoms
- Atoms consist of protons and neutrons clustered together in a nucleus and surrounded by electrons
- A neutral atom has the same number of electrons and protons. Its total charge is 0



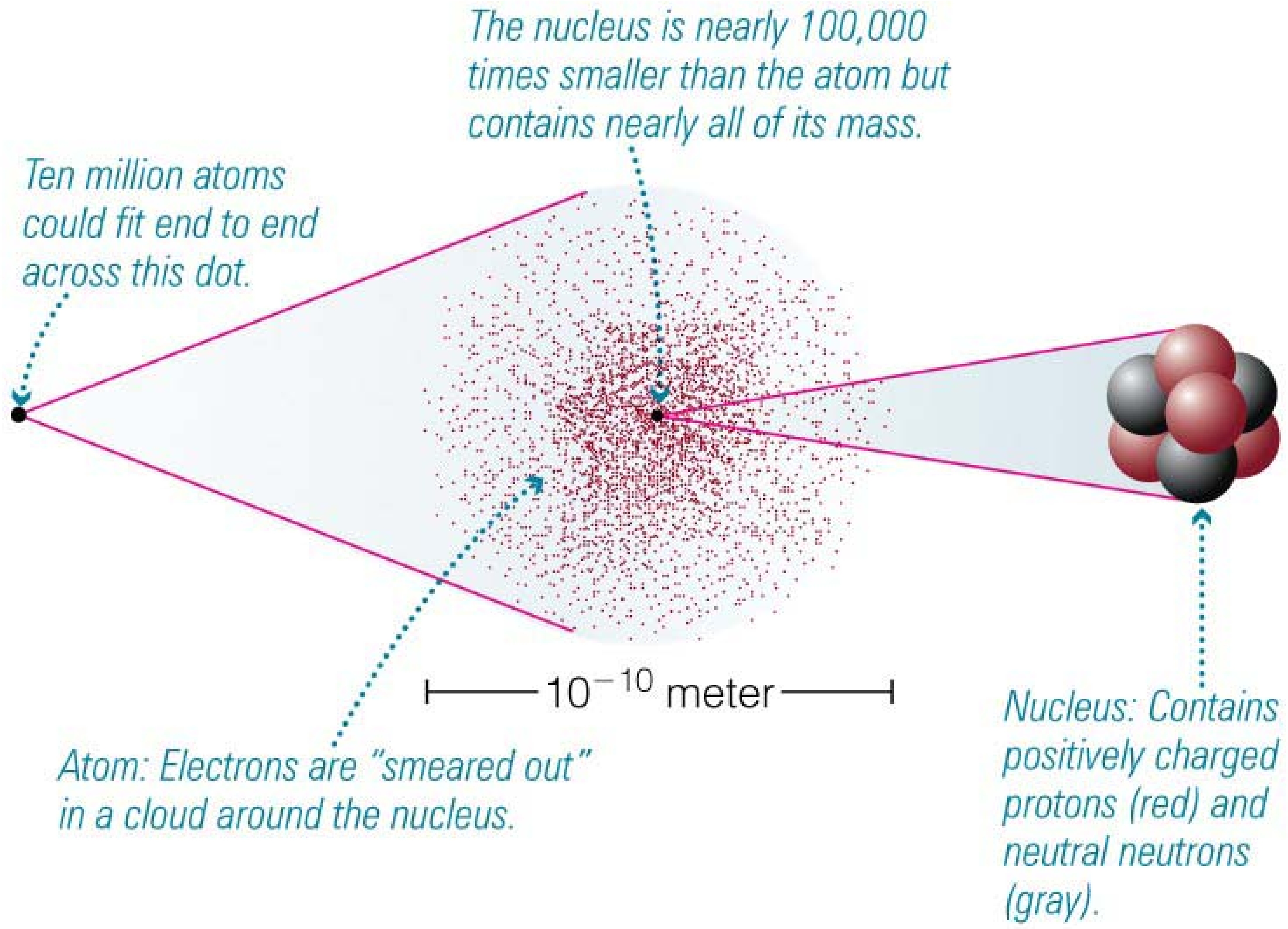


Electrons orbiting the nucleus like planets orbiting the Sun

Electrons smeared out around the nucleus like ???

Unusual Electrons

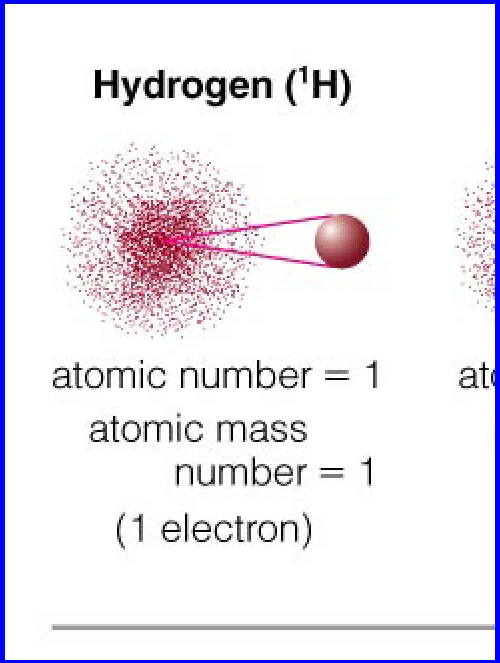
- Thinking of electrons as tiny particles doesn’t quite work
- It is impossible to precisely pinpoint the position of an electron
- Although electrons are smaller than protons, they occupy more space than a proton
- This phenomenon is caused by something called quantum physics

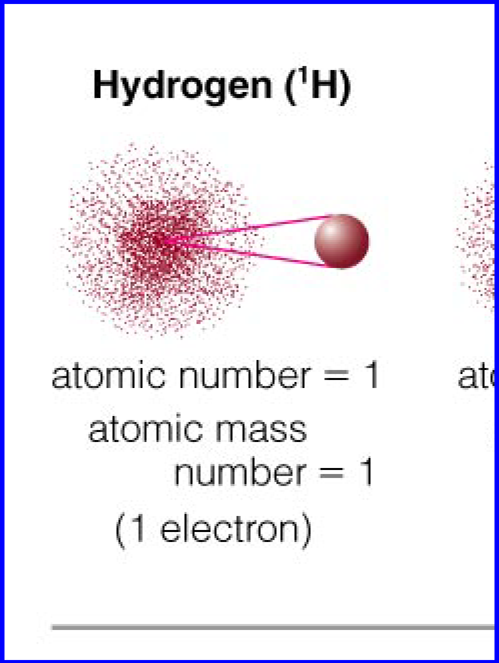


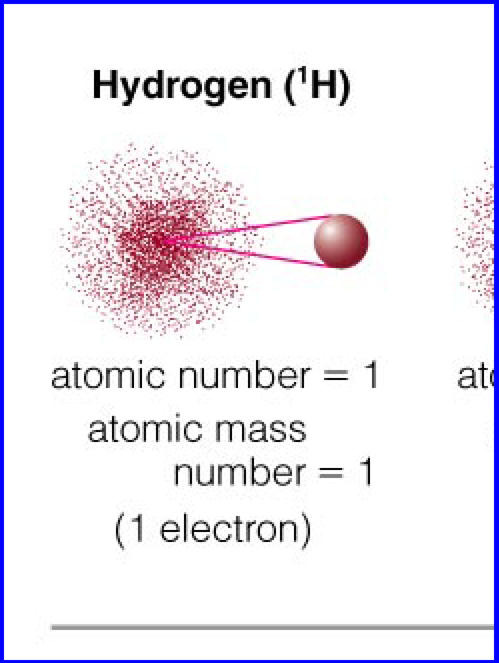
Pea / Football stadium

Space within stuff

- Almost all the mass of a table is concentrated in the tiny nuclei (plural of nucleus) of its atoms
- Why can’t I push a pencil into all that empty space?
- Forces! Electric forces keep the atoms in the table in place and prevent the pencil from pushing its way in







Identical atoms behave identically

All atoms with 6 protons, 6 neutrons, and 6 electrons behave identically

All atoms with 100 protons, 120 neutrons, and 100 electrons behave identically

Chemical Elements

- All atoms with the same number of protons are said to belong to the same “chemical element”
- Protons, not neutrons or electrons, determine what “chemical element” an atom is

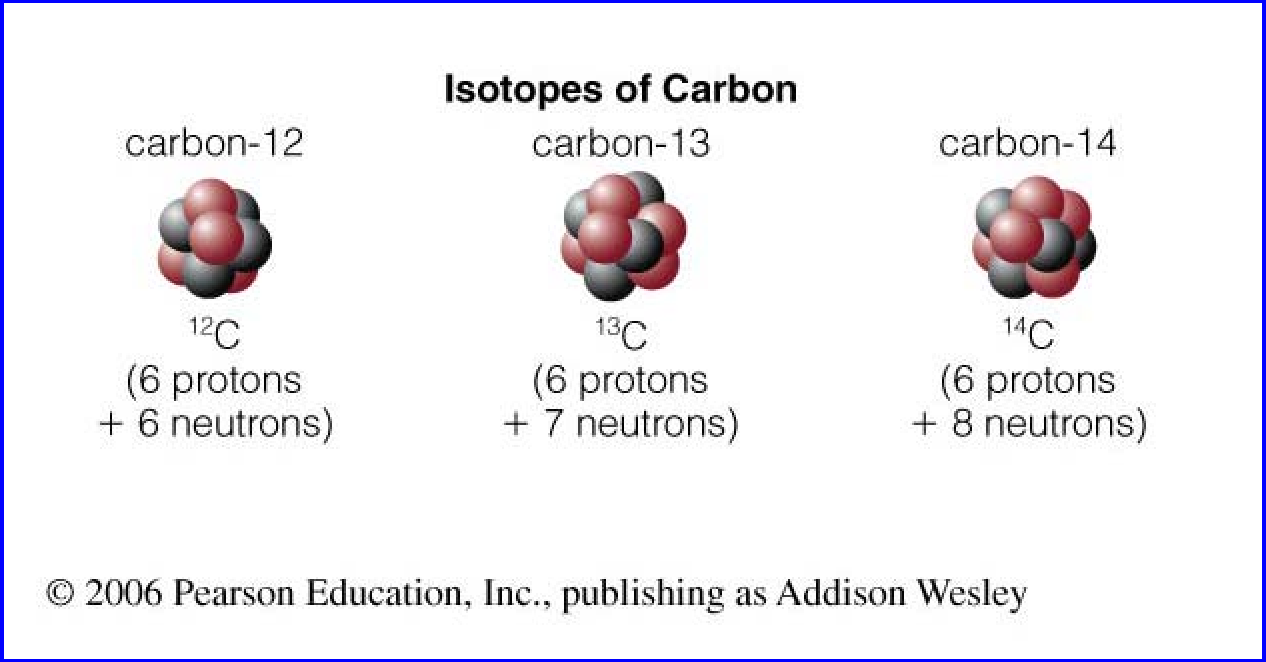
Some Chemical Elements

- Hydrogen – 1 proton, H
- Helium – 2 protons, He
- Carbon – 6 protons, C
- Oxygen – 8 protons, O

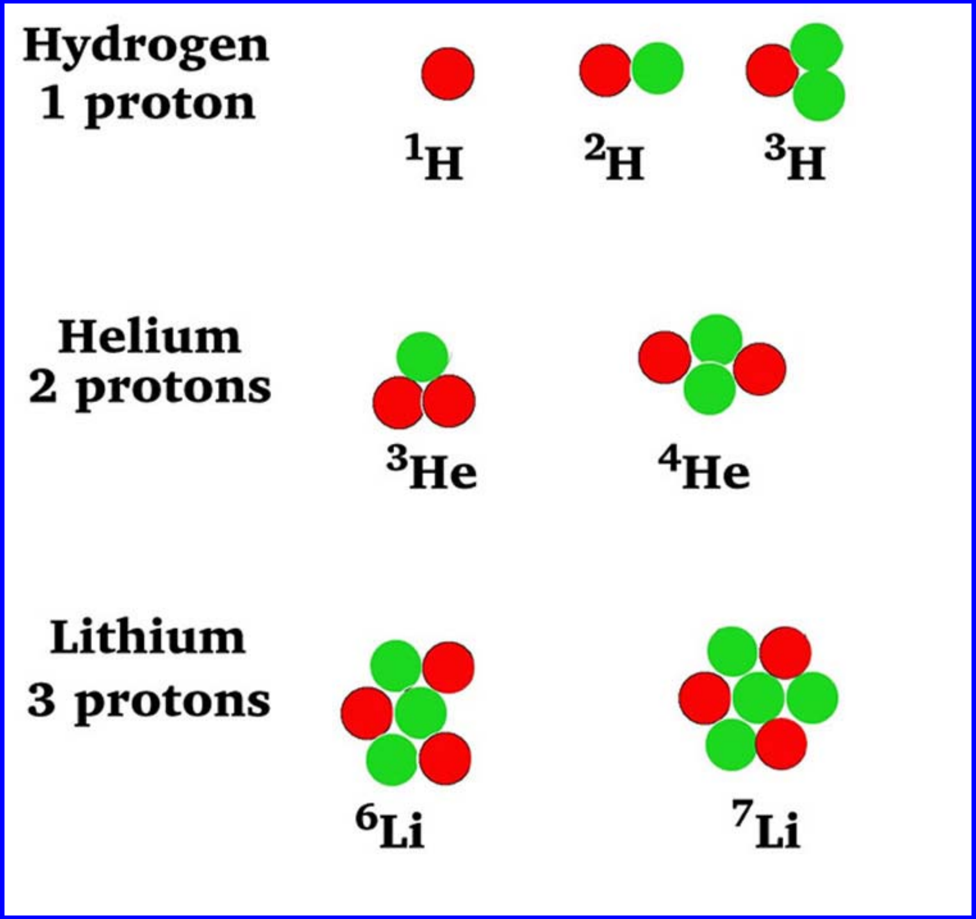
- The “atomic number” of a chemical element is the number of protons in one atom of that element

The Effects of Neutrons

- A nucleus with 6 protons does not automatically have to have 6 neutrons
- Carbon atoms can contain
  - 6 p, 6 n
  - 6 p, 7 n
  - 6 p, 8 n
  - 6 p, 20 n (this is unstable)
- The “atomic mass number” of an atom is number of protons + number of neutrons



- Different “isotopes” of a given element contain the same number of protons, but different numbers of neutrons


Hydrogen
1 proton
1H
2H
3H
Helium
2 protons
3He
4He
Lithium
3 protons
6Li
7Li

Effects of Isotopes

- All atoms of a given element have the same chemical properties, even if they are different isotopes
- The only difference between different isotopes of the same element is that some isotopes can be radioactive

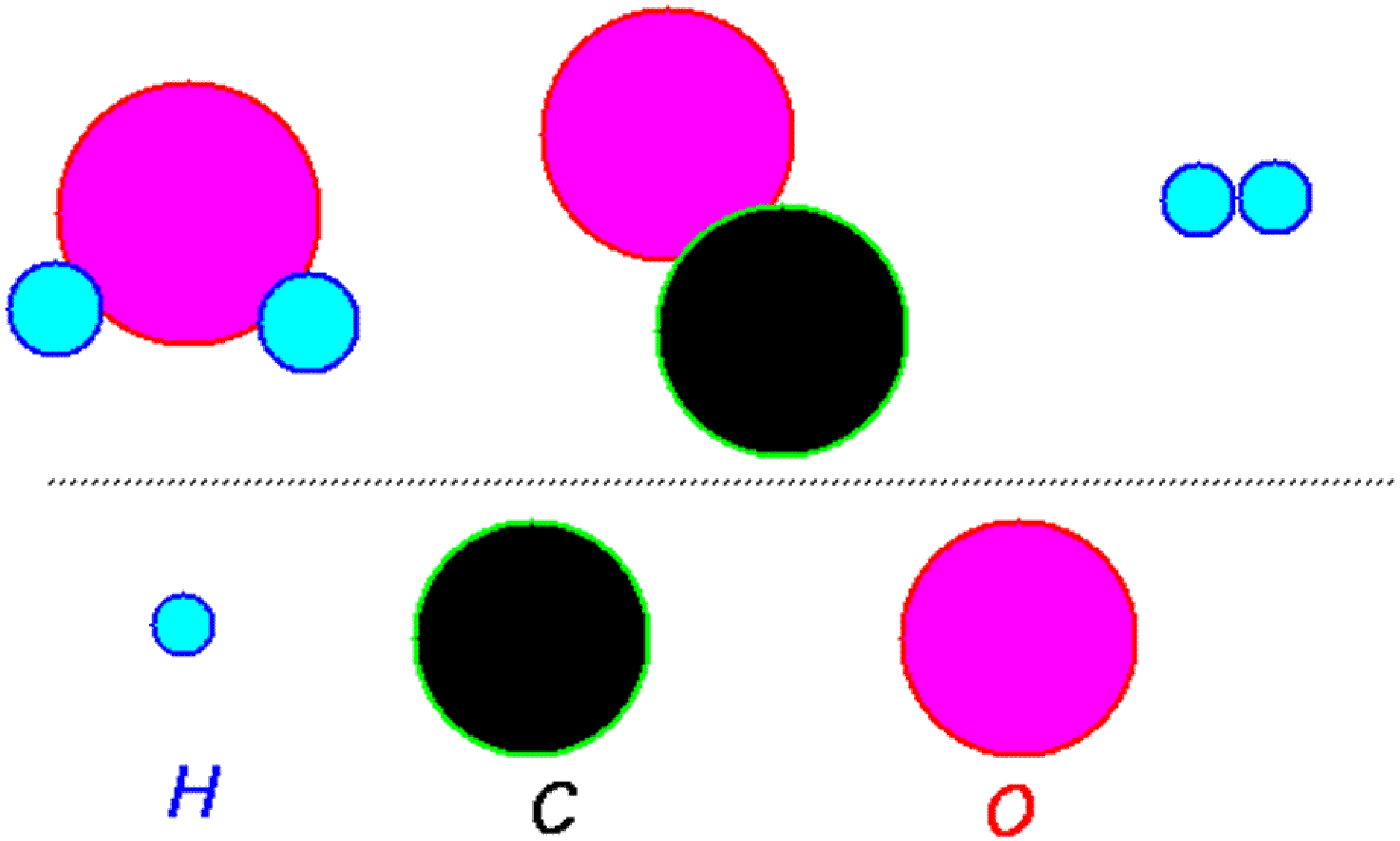
What about electrons?

- Neutral atoms have the same number of electrons as protons
- Electrons are often gained or lost
- If an atom has too many electrons, it is called a negative ion
- If an atom has too few electrons, it is called a positive ion

Joining Atoms Together

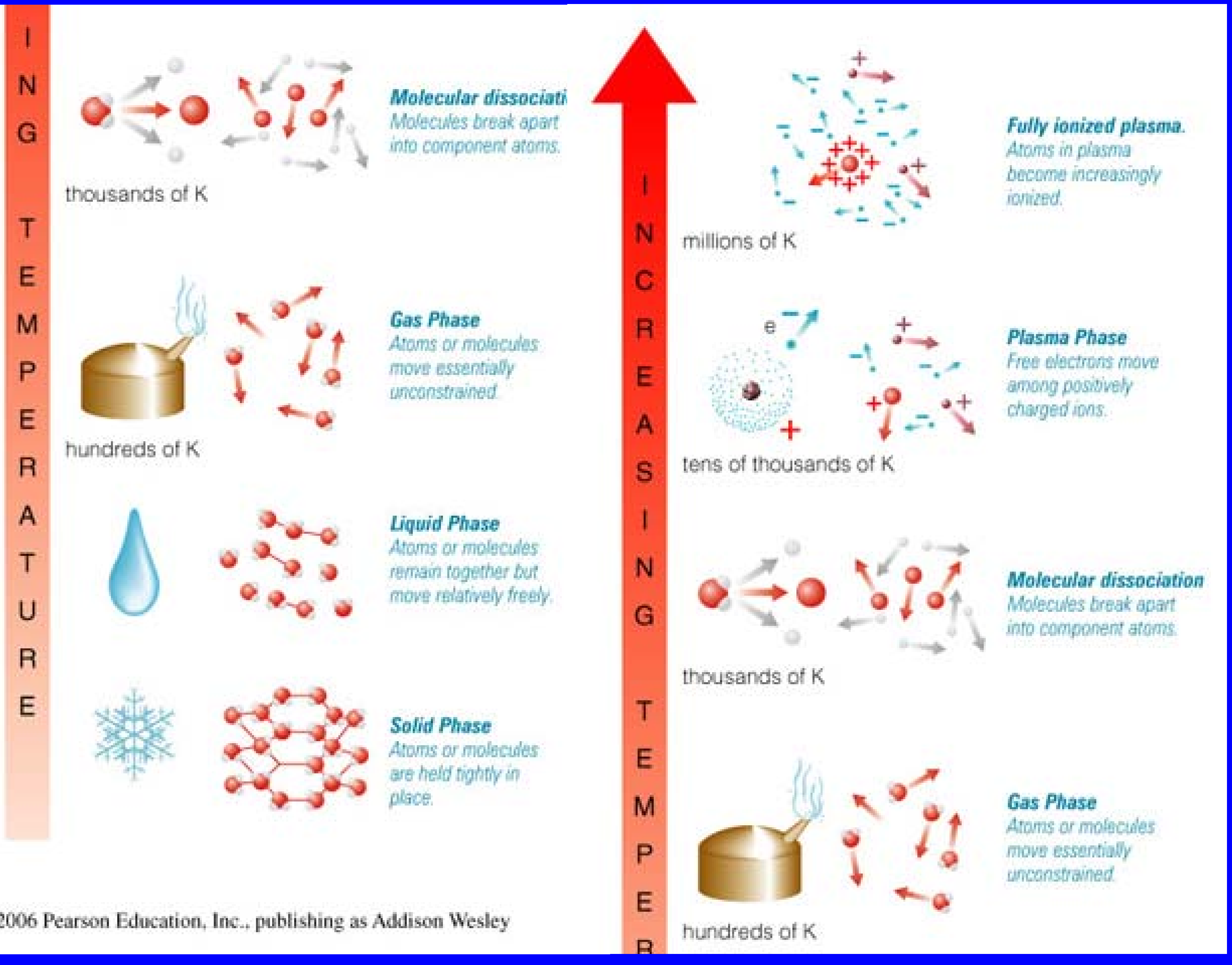
- There are just over 100 chemical elements
- There are many more substances
- Atoms can join together to form molecules that have new chemical properties

- O, O_2, and O_3 have different chemical properties
- H_2O (water) behaves differently from H or O


H
C
O

Bonds

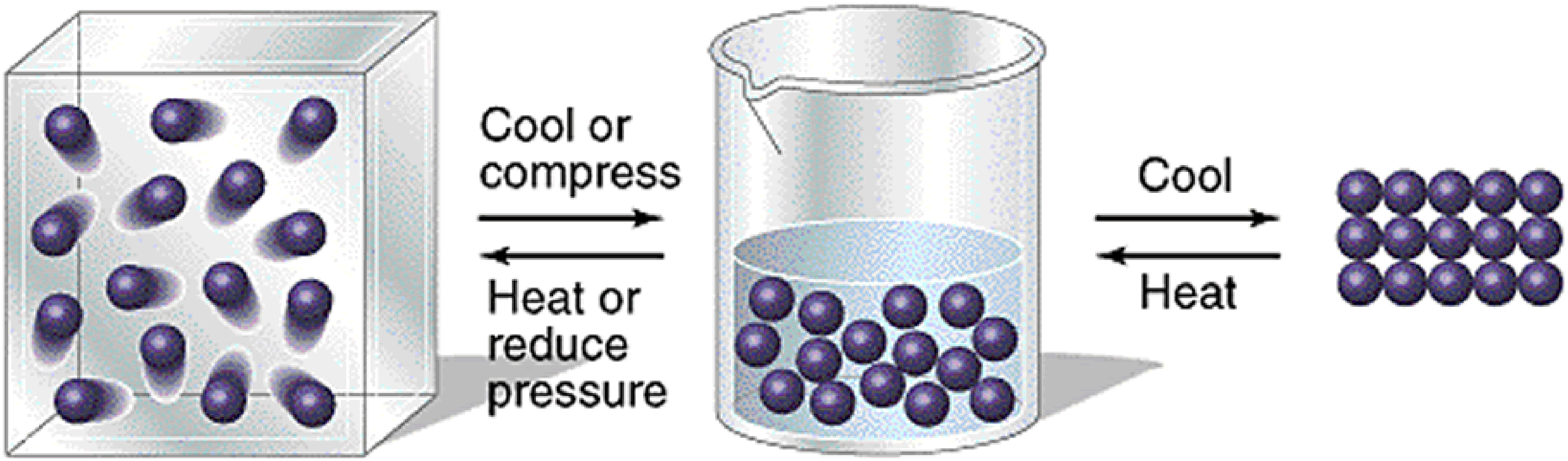
- Strong bonds join together the different atoms in a molecule
- Weaker bonds join molecules together to make an ice-cube
- The strength of the bonds joining molecules together can change, affecting the physical properties of the substance


ING TEMPERATURE
Molecular dissociati
Molecules break apart into component atoms.
thousands of K
Gas Phase
Atoms or molecules move essentially unconstrained.
hundreds of K
Liquid Phase
Atoms or molecules remain together but move relatively freely.
Solid Phase
Atoms or molecules are held tightly in place.
INCREASING TEMPER
Fully ionized plasma.
Atoms in plasma become increasingly ionized.
millions of K
e
Plasma Phase
Free electrons move among positively charged ions.
tens of thousands of K
Molecular dissociation
Molecules break apart into component atoms.
thousands of K
Gas Phase
Atoms or molecules move essentially unconstrained.
hundreds of K

Phases of Matter

- Solid, Liquid, Gas
- Higher temperatures: Solid -> Liquid -> Gas
- Lower pressures: Solid -> Liquid -> Gas

- Pressure is a force per unit area
- Liquid metal in Earth’s core
- Gas in fizzy drinks



Gas

Total disorder; much empty space; particles have complete freedom of motion; particles far apart.

Liquid

Disorder; particles or clusters of particles are free to move relative to each other; particles close together.

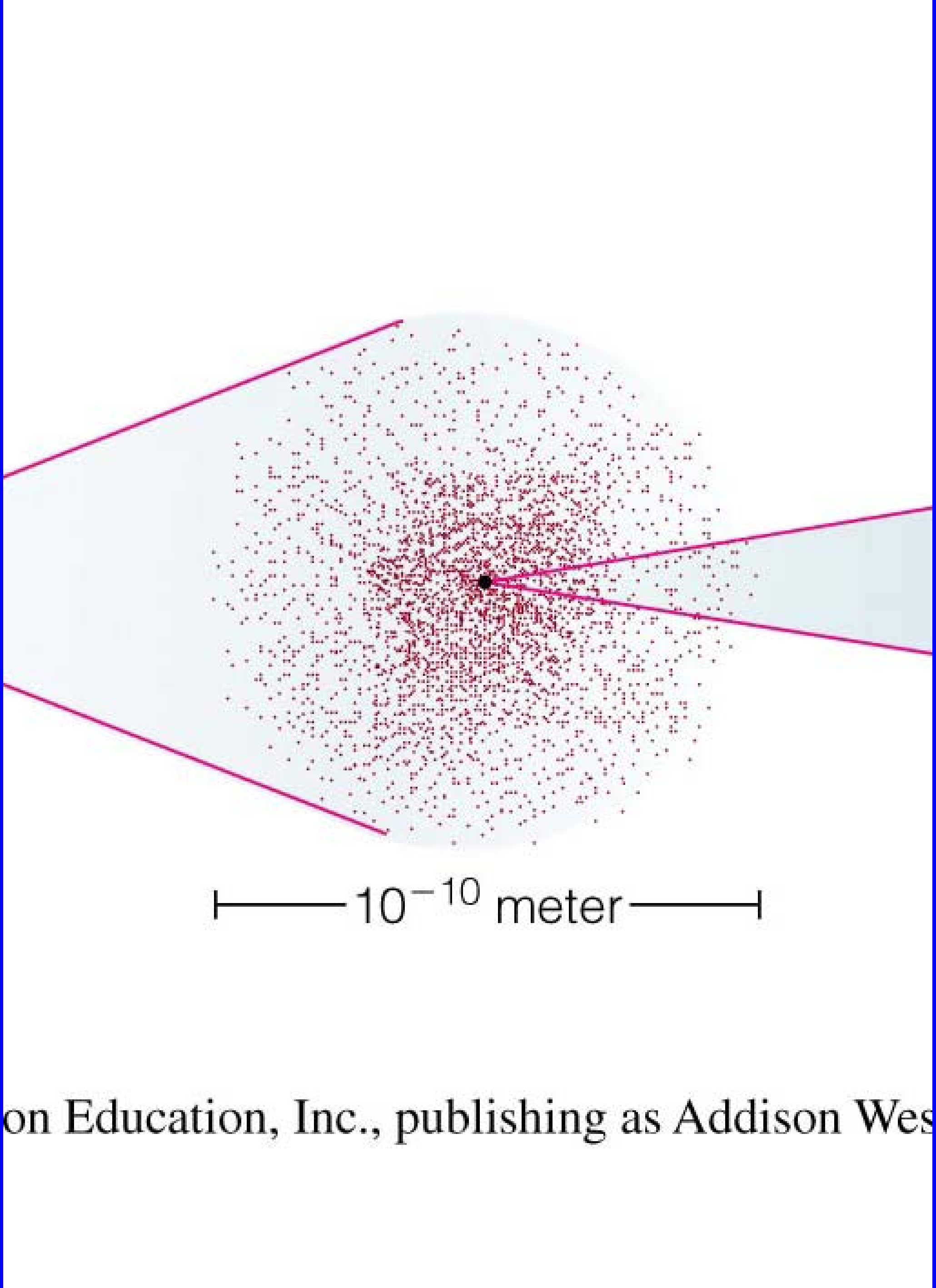
Crystalline solid

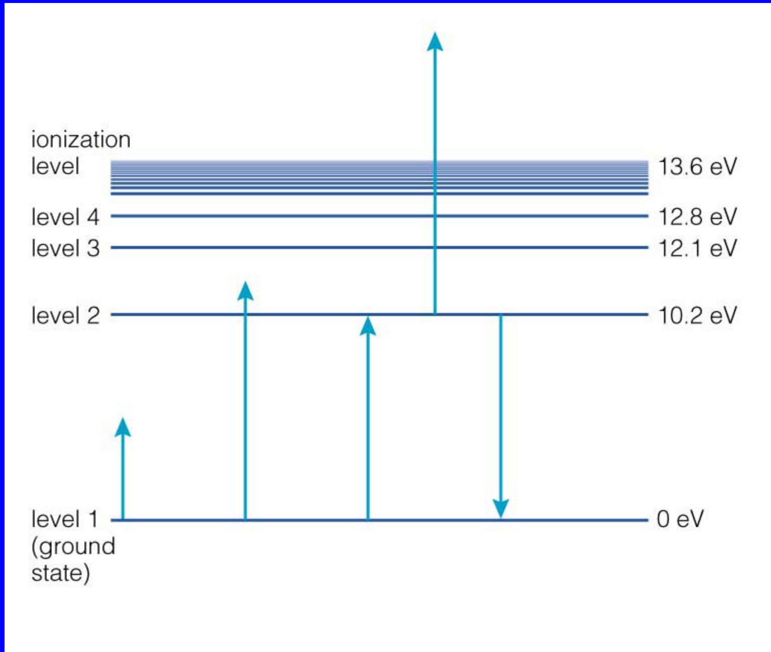
Ordered arrangement; particles are essentially in fixed positions; particles close together.

Storing Energy in Atoms

- $E=mc^2$ mass energy
- Atoms are moving, kinetic energy
- Electrical potential energy of the electrons

- The arrangement of electrons around the nucleus affects how much electrical potential energy they have



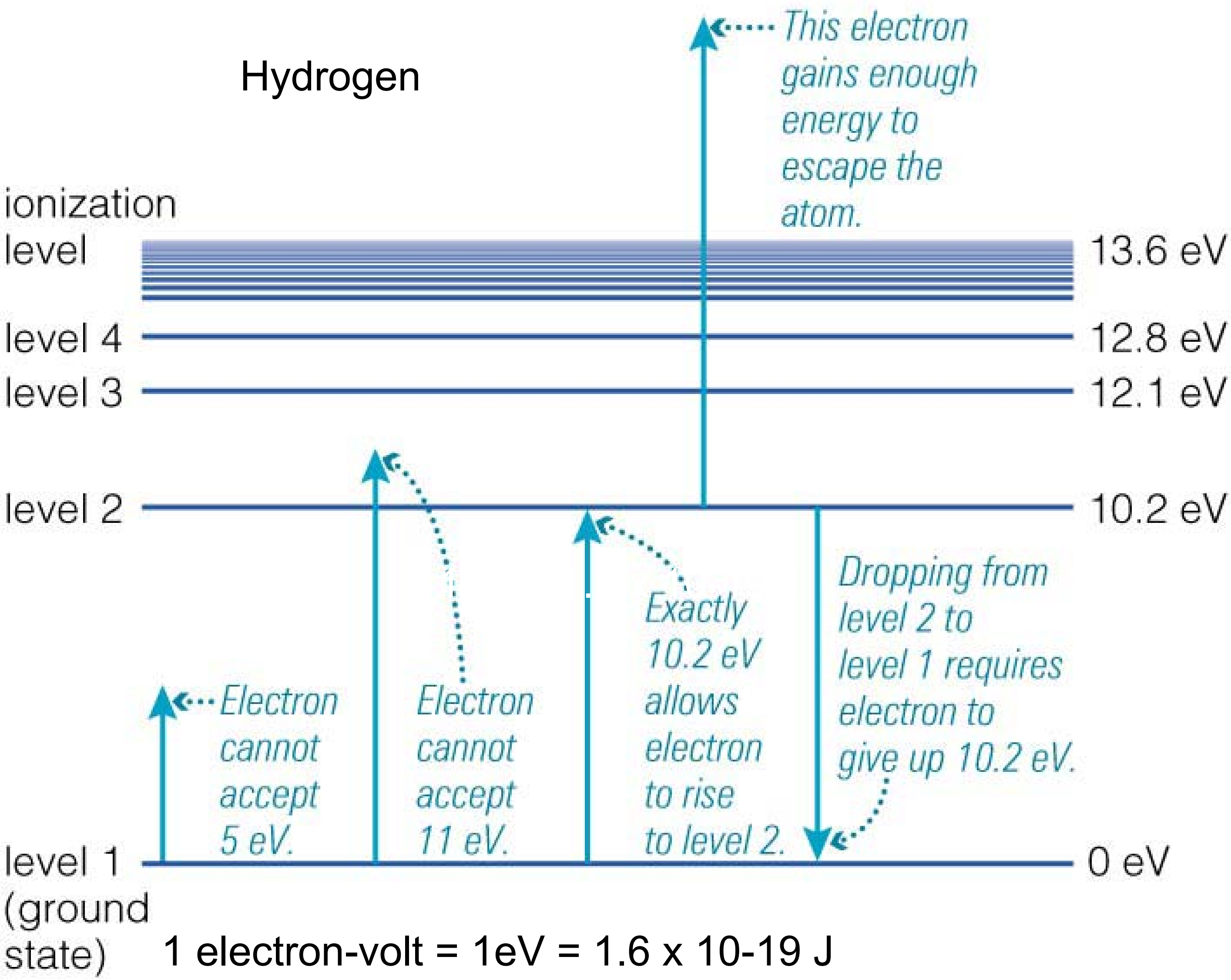


The position of an electron cannot be known exactly

The energy of an electron can be known exactly

An electron is only allowed to have particular amounts of energy
Like steps on a ladder

Hydrogen



1 electron-volt = 1eV = 1.6 x 10-19 J

Electrons gain energy when they absorb some light

Electrons lose energy when they emit some light

Energy Levels

- Different chemical elements have different energy levels
- This gives different chemical elements different "fingerprints" when they interact with light
- The electron energy is "quantized" – only certain values are allowed

Goals for Learning

- What are momentum, angular momentum, and energy?
- How can they change?
- What are atoms made of?
- How do atoms affect larger objects?
- How can atoms store energy?

Goals for Learning

- What are momentum, angular momentum, and energy?
  - Momentum = mass x velocity
  - Angular momentum = mass x velocity x distance
  - Energy is what makes matter move
  - Like velocity, momentum and angular momentum have direction

Goals for Learning

- How can they change?
  - The momentum, angular momentum, and energy of a set of interacting objects remains constant
  - These properties are conserved

Goals for Learning

- What are atoms made of?
  - A nucleus of protons and neutrons surrounded by a cloud of electrons
  - Equal number of protons and electrons
  - Nucleus is much smaller than atom
  - Protons and neutrons are much heavier than electrons

Goals for Learning

- How do atoms affect larger objects?
  - Atoms can bond together to form molecules
  - The molecules that make up a larger object control its chemical properties
  - Whether something is gas, liquid, or solid is controlled by how easily its molecules can move around each other

Goals for Learning

- How can atoms store energy?
  - Atoms store energy in electrical potential energy of their electrons
  - Electrons are only allowed to possess certain amounts of energy
  - Electron energy levels are quantized

- http://www.yourdictionary.com/images/ahd/jpg/A4atom.jpg
- http://www.ux1.eiu.edu/~cfadd/1160/Ch30Nuc/Images/nuc2.gif