CHAPTER 9: GRAVITY 01/10/19

THE UNIVERSAL LAW OF GRAVITY

- Isaac Newton had a revolutionary insight: that the force between the Earth and an apple is the same one as that between planets, moons and everything else in the universe. Namely that gravity is universal.
- An apple falls to Earth because gravity pulls it. The moon falls as well due to gravity, but because it already has enough tangential velocity, gravity causes it to fall away from the straight line it would otherwise follow. In other words, the moon falls around the Earth.
- Everything pulls on everything else with a force directly proportional to the product of their masses and inversely proportional to the square of the distance separating them.
    - $F \alpha m_1m_2/d^2$, $F = Gm_1m_2/d^2$
    - $G = 0.0000000000667\ N{\cdot}m^2/kg^2$
    - The force between two 1 kg objects 1 meter apart is 0.0000000000667 N – extremely weak!

THE INVERSE SQUARE LAW

- FIG: 9.5
    - Thickness of a layer of paint from a paint spray can will decrease as the square of the distance from the can to the surface (e.g. layer is ¼ as thick if the surface is twice as far from the can).
- FIG: 9.6
    - The *d* in Newton's equation is the distance between the objects' centers of mass.
    - Because of the inverse square law, the strength of gravitational force decreases quite suddenly as the distance increases, but then almost levels off at a very small amount at large distances.

WEIGHT AND WEIGHTLESSNESS

- What does a bathroom scale measure? Your weight (the force due to gravity on you) or the support force of the compressed spring in the scale?
    - What happens to the scale reading in an accelerating elevator?
        - FIG: 9.9
        - Your measured weight changes depending on how much support force is there on you, although the force due to gravity on you has not changed.
- Modify our definition of what we understand and experience as weight.
    - Old: force due to gravity on a body
    - New: force a body exerts against a supporting object
        - Under this definition, your weight is what you feel it to be
- Astronaut is weightless, not because there is no gravity, but because he is in free fall.
    - A skydiver is momentarily weightless when she first steps out of the plane. As soon as she starts experiencing air resistance, she regains some

weight because the air is partially supporting her. Her ‘normal’ weight during a jump will be felt when she is at terminal velocity, i.e. when she is supported by the same amount of force that gravity is pulling on her.
    - Weightlessness is the feeling you get in a car going too fast over the top of a hill, or in a roller coaster just as you drop over a hill.

TIDES

- Tides are caused by the differences in the gravitational pull on an object from one side of the object to the other.
    - Gravitational force between the moon and Earth is stronger on the side of the Earth facing the moon and weaker on the side farthest from the moon.
        - This is because the gravitational force gets weaker with distance according to the inverse square law.
    - FIG. 9.14: Like someone pulling on one sleeve of your coat instead of the whole coat at one time.
    - FIG. 9.15
        - DEMO: Earth globe and moon ball display
- This tidal force elongates the Earth into a football-like shape.
    - Mainly the elongation is in the bulging of the oceans on the near and far side. The bulges average about 1 meter above the average ocean level.
    - FIG. 9.19
        - The solid Earth spins beneath these water bulges, so we get two sets of tides a day – one for each bulge that we pass under as we spin around once.
    - The tides don’t occur at the same time because the moon advances in its orbit during the 24 hours it takes the Earth to rotate, so we need an extra hour to “catch up” to the moon.
        - DEMO: spinning of moon on axis as it rotates.
- Why is the moon responsible for the tides if the sun has a much stronger gravitational pull on the Earth?
    - FIG. 9.16: Tides are caused not by the absolute strength of the force, but rather the size of the *difference* in the force from one side of the object to the other.
        - The sun’s pull on the Earth is 180 times greater than the moon’s pull on the Earth.
        - The sun’s pull changes by only 0.017% from one side of the Earth to the other because it is so far away.
        - The moon’s pull on the Earth changes by 6.7% from one side to the other because it is so much closer.
        - $6.7\% \times F_{moon} > 0.017\% \times F_{sun} = 0.017\% \times 180 \times F_{moon} = 3\% \times F_{moon}$
- Higher than average tides when Earth, moon, and sun line up: ***spring tides***.
    - FIG. 9.17: Occurs during full and new moons. Greater during an eclipse.
    - DEMO: Earth globe, sun ball, and moon ball display
- Lower than average tides when moon is at right angle to Earth-sun line: ***neap tides***.
    - FIG. 9.18: Occurs during half moons.

    - DEMO: Earth globe, sun ball, and moon ball display
- Microtides occur in our bodies
    - Dominated not by the moon, but by the tidal forces from the Earth and other massive objects nearby (buildings, mountains).
        - Moon's force doesn't change much from one side of our body to the other because it is so far away and we are so small.
        - Only objects relatively near contribute.
    - The tidal force on your body from a 1 kg melon held 1 meter over your head is 200 times stronger than the tidal force from the moon on your body.
        - The tidal forces from the alignment of stars and planets have no effect on you regardless of what astrologers say.

CHAPTER 11: THE ATOMIC NATURE OF MATTER 01/11/19

THE ATOMIC HYPOTHESIS

- The idea that matter is composed of atoms goes back to the ancient Greeks, like Democritus (*atomos* (Gk) – indivisible). Unfortunately, Aristotle didn't buy it, and that was the end of the idea for the next 2000 years.
- Atomic idea revived in the 1800's by John Dalton explaining chemical reactions and Robert Brown observing unexplained jiggling of microscopic particles (Brownian motion).
- Brownian motion explained in 1905 by Einstein, and it was at this point that the atomic hypothesis was widely accepted.

ATOMS

- All matter is made up of atoms
- There are only 118 known elements, 98 are naturally occurring, the rest are man-made.
    - These are the **elements** of the **periodic table**.
        - FIG: 11.9
    - Elements 116 and 118 were "discovered" in 1999, but the finding was retracted when the results were found to be fraudulent.
    - Hydrogen [H] accounts for more than 90% of all the atoms in the universe. Most of the rest are helium [He].
    - Living things are made mostly of just five elements: [H], carbon [C], oxygen [O], nitrogen [N], and (for lots of animals) calcium [Ca]
    - 99% of the substances of Earth are made up of only about a dozen elements: [H], [C], [O], [N], [Ca], sodium [Na], magnesium [Mg], aluminum [Al], silicon [Si], phosphorous [P], sulfur [S], chlorine [Cl], potassium [K], iron [Fe]
- Atoms are small
    - An atom is as many times smaller than you as you are smaller than the sun
    - The diameter of an atom is to the diameter of an apple, as the diameter of an apple is to the diameter of the Earth
- Atoms are numerous
    - There are as many atoms in a thimbleful of water as there are thimblefuls of water in the oceans – 10^{23}, or 100,000,000,000,000,000,000,000!
    - There are as many atoms of air in your lungs as there are breaths of air in the whole world
- Atoms are ageless
    - Hydrogen was formed shortly after the Big Bang (13.7 billion years ago). All other atoms came from the burning or explosion of stars.
    - Many atoms in your body are nearly as old as the universe and all the atoms are constantly recycled from person to person, around the world and throughout the universe.

WHAT ARE ATOMS MADE OF?

- Atoms are not "indivisible" as some early Greeks thought. They are made up of smaller particles.
  - **Electron**
    - Many early clues about electricity (Greeks: static electricity on amber, Franklin: electric current or flow, etc.) led to J.J. Thomson's discovery that cathode (electric) rays are made of individual particles he named electrons.
    - Electron was later found to have a single smallest unit of negative electric charge and a mass 1/2000 the mass of hydrogen.
  - **Nucleus**
    - Ernest Rutherford shot positively charged alpha particles, which are as massive as a helium atom, at a gold foil and expected them to pass right through since electrons are so light. Some of them were greatly deflected, some even backwards. This meant that there was something positively charged and very massive at the center of the atom. The rest of the atom is empty space! The nucleus contains nearly all of the mass (except the very light electrons), but very little of the volume. There are two types of particles in the nucleus
    - **Proton**: positive charge of equal magnitude as the electron charge, 2000 times more massive than an electron
    - **Neutron**: neutral (no charge), 2000 times more massive than an electron
    - Protons and neutrons are actually made up of smaller particles called quarks.
- **Atomic model**: a scientific model is an abstraction that helps us visualize and make predictions about unseen portions of nature.
  - A beginner's model of the atom is the classic planetary model with a central nucleus and orbiting electrons. It shouldn't be taken literally; it is not reality. It just helps us think about the atom. For example, electrons don't orbit. It is more like they swarm or are smeared around the nucleus in shells.
  - FIG. 11.6: The arrangement of electrons in these shells determines the atom's chemical properties.
  - It is the repulsive electric forces between electrons from different atoms that keep us falling through the empty spaces of atoms when we sit on a chair or push on a wall. When we touch, we never actually make physical contact. Atoms never actually "touch" except in nuclear fusion.
    - DEMO: magnets pushing.
- **Atomic number**: the number of protons in an atom. Periodic table is arranged by atomic number. Also the number of electrons in a neutral atom.
- **Atomic mass number**: the number of protons and neutrons in an atom. There can be different numbers of neutrons in an atom. Those are called **isotopes** of the element.

ELEMENTS, COMPOUNDS, MIXTURES, AND MOLECULES

- Elements: substances composed of a single kind of atom (solid gold, liquid mercury, neon gas)
- Compounds: substances made up of elements that are chemically combined by sharing electrons. Chemical properties of a compound are different than those of the elements that make it up (because the arrangement of electrons has changed).
    - Table salt (NaCl): sodium (Na) is explosive around water, chlorine (Cl) is a poisonous gas, NaCl is harmless table salt.
    - H_2O: at room temperature, water is a liquid, but hydrogen and oxygen are combustible gases.
- Mixtures: substances made up of elements mixed together without chemically combining.
    - Air: nitrogen, oxygen, argon, carbon dioxide, etc. Each individual gas still acts the same in air. (also dirt, soup, etc.)
- Molecules: many compounds are made up of molecules.
    - The smallest unit of a substance consisting of two or more atoms held together by sharing electrons.
    - Water (H_2O), ammonia (NH_3), carbon dioxide (CO_2), carbon monoxide (CO)
    - By combining elements in different ways, there can be an unlimited number of possible molecules.

OTHER MATTER

- Antimatter
    - All particles have antiparticle partners. Antiparticles have the same mass (and some other properties) as their particle partners, but are opposite in other properties such as electric charge.
        - e.g. the anti-electron, or ***positron***, has the same mass as the electron, and its charge has the same magnitude but opposite (positive) sign.
    - Gravity treats matter and antimatter the same, and they both look the same. Only subtle nuclear effects can distinguish them at a distance.
        - It appears that all the galaxies, stars, etc. that we see are matter.
    - When matter and antimatter meet, they annihilate each other, converting all their mass into radiant energy according to $E=mc^2$.
- Dark Matter
    - Some type of unknown matter that we cannot see, yet it has gravitational effects on stars and galaxies that we do see.
    - Don’t know what it is, but it is not ordinary matter made of elements, quarks, electrons, etc.
    - Makes up ~27% of the universe
- Dark Energy
    - Some type of unknown energy that pushes outward on the universe, making it expand faster and faster.
    - Makes up ~68% of the universe.

CHAPTER 12: SOLIDS 01/11/19

CRYSTAL STRUCTURE

- Solids are classified according to how their atoms are arranged into fixed positions. There are two basic classes of solids:
    - Crystalline: atoms are arranged in a 3-dimensional, orderly latticework (salt, metals, most minerals)
        - DEMO: crystal models
    - Amorphous: atoms and molecules are distributed randomly, disordered (rubber, plastic, glass)

DENSITY

- DEMO: will it float?
- Density is not the massiveness or bulkiness of a substance. It is the massiveness per bulkiness, or how much mass occupies a given space. More precisely, it is the mass per unit volume.
    - Density = mass/volume
    - Density is a fundamental, distinguishing property of a solid or liquid.
- FIG: table of densities
    - Water is 1000 kg/m^3 or 1 g/cm^3
    - Materials with greater density sink in water (e.g. aluminum at 2.7 g/cm^3), materials with lesser density rise in water (e.g. ice at 0.92 g/cm^3)
- DEMO: identify aluminum, iron, brass pieces
- CHECK QUESTIONS:
    - Which has greater density:
        - Cupful of water or lake-full of water?
        - kilogram of lead or a kilogram of aluminum?
        - 100 kg of lead or 1000 kg of aluminum?
        - Single uranium atom or the entire Earth?
    - Which weighs more: a liter of liquid water or a liter of ice?
    - What is the density of 1000 kg of water?
    - What is the volume of 1000 kg of water?

ELASTICITY

- When external forces are exerted on a solid, there are different kinds of changes in size and shape that the object can undergo. These changes depend on the arrangement of atoms in the material and how they are bonded together.
- DEMO: weight hanging from a spring
- Elasticity is the property of changing shape when a deforming force acts on an object and returning to the original shape when the deforming force is removed.
    - *Elastic* materials return to their original shape (steel spring, baseball, bow)
    - *Inelastic* materials do not return to their original shape after being deformed (clay, lead)
- Most elastic materials obey Hooke's Law, which says that the amount of stretch or compression, x, is directly proportional to the applied force, F:
    - $F = kx$

        - *k* is a number called the spring constant, which has a different value for different springs or materials.
    - DEMO: hang different weights from the spring and measure *x*.
    - An elastic material can be stretched or compressed past its ability to return to its original shape, at which point it is permanently deformed. The distance at which this happens is called the *elastic limit*.

TENSION AND COMPRESSION

- *Tension*: when something is pulled or stretched
- *Compression*: when something is pushed or squashed
- DEMO: bend a meter stick
    - CHECK QUESTION: where is the tension and where is the compression? Is there a place where there is neither tension nor compression?
- DEMO: simple & cantilever beams – where are tension, compression, neutral
- CHECK QUESTION: Why are I-beams not called H-beams? Why do I-beams exist – why not use rectangular beams?
- Stone and brick break more easily under tension than compression.
- CHECK QUESTION: Why does the Parthenon have so many columns? Why are ancient doorways, bridges, etc. supported by arches?
    - FIG: 12.12, 12.13, 12.14, 12.15
- With the right shape, arches do not need any cement or buttressing. An arch supporting only its own weight is in the shape of a catenary – the same shape a rope or chain has when you dangle it from both ends (FIG: 12.14, St. Louis Arch)

SCALING

- DEMO: spherical vs cylindrical flask
- Length, area, and volume of objects do not scale the same. As the length of an object grows, the area (cross-sectional area and surface area) of the object grows by the length squared, and the volume grows by the length cubed. Area grows faster than length and volume grows faster than area.
    - DEMO: blocks
    - FIG: 12.16, 12.18
- Strength is proportional to cross-sectional area.
- Weight is proportional to volume.
- Heat transfer, air resistance, diffusion into cells, is proportional to surface area.
- CHECK QUESTIONS:
    - Why do small animals have thin legs and large animals have thick legs?
    - Why do elephants have big ears? Why are Indian elephants' ears smaller?
    - Why must special care be taken to keep babies warm?
    - Why is food for stir-frying in a wok cut into small pieces?
    - Why do coal chunks burn while coal dust explodes?
    - Why can an insect jump out of a tree to the ground, but you can't?
    - Why do cells divide? Why aren't an elephant's cells bigger than an ant's?
    - Why do large animals have slower heartbeats than small animals?
        - All warm blooded animals have about the same life span in heartbeats except humans, who live 2-3 times longer.

CHAPTER 13: LIQUIDS 01/14/19

LIQUID CHARACTERISTICS

- Liquids flow, they are *fluids*. Their molecules move freely around and over each other.
    - Liquids take the shape of their container.
- Liquid molecules are actually quite close together and are very hard to compress.

PRESSURE

- Pressure is the force per unit area, i.e. the force exerted divided by the area on which the force acts.
    - Pressure = force/area
- DEMO:
    - Two blocks on a table, one on side, one on end
    - Push you with a force of 1 N with my finger or a pin
    - Bed of nails
    - Why should knives be sharp?

LIQUID PRESSURE

- Pressure in a liquid depends only on the density and depth of the liquid.
    - Due to the weight of the liquid above (Derive from F/a to den × depth)
- Would you rather use your finger to plug a leak 1 m below sea level in a dike on the Atlantic Ocean, or a leak in the plumbing on the first floor of a pipe draining a second floor bathtub?
    - FIG. 13.4: Amount (volume) of water not important (damming a large shallow lake vs. a small deep one).
- Pressure is exerted equally in all directions – not just downward (because liquid flows). Net force is directed perpendicular to surfaces.
    - DEMO: sideways pressure: water spouts out of holes in a container
    - DEMO: upwards pressure: a floating block

BUOYANCY

- Depth dependence of liquid pressure causes buoyancy: the apparent loss of weight experienced by submerged objects.
- FIG: 13.9: pressure is greater on the bottom of objects (at greater depth) than it is on the top (at lesser depth). Therefore, upward forces are greater than downward forces – a net force upward.
- A completely submerged object displaces a volume of liquid equal to its own volume.
    - DEMO: measure object volume by dropping object in water and measuring rise of water
- Archimedes' Principle: an immersed body is buoyed up by a force equal to the weight of the fluid it displaces.
    - DEMO: hang block from scale and lower in water and alcohol

    - The buoyant force is due to the weight of the displaced fluid. That weight depends on the volume displaced (equal to the volume of the object immersed) and the density of that displaced fluid (weight = density × volume). Denser liquids provide greater buoyant forces.
- CHECK QUESTIONS:
    - Lead and aluminum blocks of identical size are submerged in water. Upon which is the buoyant force greater?
    - Lead and wood blocks of identical size are submerged in water. Upon which is the buoyant force greater?
    - Is the buoyant force on an object equal to the weight of the object or the weight of the fluid displaced?

FLOTATION

- The weight of an object does play a role in flotation, however. Whether an object floats depends on how the buoyant force compares to the weight of the object, and the weight of the object depends on its density.
- Will an object float in a fluid?
    - If object is denser than fluid, it sinks.
    - If object is less dense than fluid, it rises.
    - If object has density equal to fluid, it neither sinks nor rises – it floats in place.
    - 9 out of 10 people who can't float are male. Men are dense as well as unstable!
- A floating object displaces a weight of fluid equal to its own weight.
    - How does an iron ship float? By making a bowl shape, it spreads the weight of its iron through a much larger volume, thereby reducing the *ship's* overall density. The deeper the iron bowl is immersed, the greater volume (weight) of water is displaced until the buoyant force equals the weight of the iron. Then it stops sinking.
    - DEMO: float an object in a full beaker on a scale. Weight of overflow is exactly matched by the weight of floating object.
- CHECK QUESTION: What happens to a ship that sails from the Gulf of Mexico into the Mississippi River? What would happen if it sailed into a lake of mercury? Alcohol?
- Fraction of a floating object that is submerged equals the fraction of the object's density compared to the fluid in which it floats.
    - Icebergs: 92% submerged (density of ice/density of water = 0.92)

CHAPTER 14: GASES 01/14/19

GAS CHARACTERISTICS

- Gases flow, they are *fluids*. Their molecules move freely around and over each other.
  - Gases expand to fill their container.
- Gas molecules are far apart and are easily compressed.

ATMOSPHERE

- If gases expand indefinitely to fill a container, then why doesn't the atmosphere fly away into space?
  - Gravity pulls the air molecules toward Earth, the heat from the sun gives the molecules kinetic energy that makes them tend to fly away. The thickness of the atmosphere is determined by the balance of these two effects.
- FIG: 14.1: Air is more compressed at sea level than at higher altitudes – i.e. the density of a gas is depth dependent. The density is greater at greater depths. This is a fundamental difference between gases and liquids.

ATMOSPHERIC PRESSURE

- What weighs more: a grapefruit in your refrigerator or the air in your refrigerator?
- At sea level 1 cubic meter of air has a mass of 1.25 kg – almost 3 pounds of weight! We don't feel it because we're immersed in an ocean of air (you don't feel the weight of a bag of water that you hold underwater).
- Consider a bamboo pole with a 1 cm^2 cross section that extends 30 km into the upper reaches of the atmosphere. The mass of air in the pole would be about 1 kg; its weight is 10 N. The pressure from this weight is 10 N/cm^2, or 100,000 N/m^2, or 14.7 lb/in^2.
  - How much weight is on a 1 m^2 sheet of paper? 100,000 N or 22,000 lbs.
- DEMO: crushing a soda can with atmospheric pressure.

BAROMETER

- A barometer is an instrument for measuring atmospheric pressure. A barometer "balances" when the pressure from the weight of the liquid inside the tube equals the atmospheric pressure outside. A 76 cm column of mercury weighs the same as a 30 km column of air. When the air pressure increases, more mercury is pushed back into the tube. When it decreases, more mercury flows out of the tube.
  - How tall would a water barometer have to be?
  - How does a straw work? You reduce air pressure in the straw by expanding your lungs. The atmospheric pressure, which is now greater than the pressure in the straw, pushes liquid up the straw into your mouth.
  - DEMO: sucking through two straws, one out of the liquid.

BUOYANCY OF AIR

- Is atmospheric pressure really depth dependent? Yes, a helium balloon rises due to greater pressure at its bottom relative to its top – buoyancy!
  - Archimedes' Principle for air: An object surrounded by air is buoyed up by a force equal to the weight of air displaced.
  - Objects less dense than air will rise, objects more dense will sink.
  - Is the buoyant force of the atmosphere greater on a helium balloon or elephant?
- How far up will a submerged cork rise in a glass of water? To the top.
- How far up will a helium balloon rise in air? It will rise only as long as it displaces a weight of air greater than its own weight. But air gets less dense with altitude, so a lesser weight of air gets displaced for a given volume as the balloon rises. It will rise until it reaches a point where the density of the air matches the average density of the balloon.
- What happens to a helium balloon that rises high in the atmosphere? It breaks because the air pressure outside the balloon drops, and the balloon will expand until it bursts.
- Which will rise higher: a rigid helium balloon, or one that is free to expand?

BERNOULLI'S PRINCIPLE

- Streamlines are the smooth paths of bits of moving fluid. The motion of fluids follows streamlines. Streamlines crowd closer together in regions where the fluid flow speed is greater, like through narrow regions.
  - FIG: 14.17
- Bernoulli's Principle: Where the speed of a fluid increases, internal pressure in the fluid decreases.
  - FIG: 14.18
- Examples:
  - Wind over a roof. FIG: 14.19
  - DEMO: blowing over the top of a sheet of paper
  - Convertible top
  - Umbrella in the wind
  - Airplane wing FIG: 14.20
  - Higher waves on windy days
  - Baseball curve FIG: 14.21
  - DEMO: soda cans rolling together on straws
  - DEMO: ping-pong ball in hair dryer stream
  - DEMO: beach ball and leaf blower