Conceptual Physics

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Table of Contents

- Mechanical energy is ability of object to do work
- Mechanical energy ☞ { kinetic (energy in motion)
potential (energy that is stored)
- Object's kinetic + potential energy ☞ object's mechanical energy
- Difference between kinetic and mechanical energy
  - Kinetic is a type of energy
  - Mechanical is a form that energy takes
- E.g. of mechanical energy { bow that has been drawn
bow that is launching an arrow
  - However ☞ they do not both have same type of energy
  - Drawn bow ☞ example of potential energy
  - Bow in motion ☞ example of kinetic energy
  - If the arrow strikes bell
    some of its energy will be converted to sound energy
  - It will no longer be mechanical energy
    but it will still be kinetic energy

- Kinetic energy of molecules moving in a random way
- *Faster* they move ☞ higher the *temperature*
- Thermal energy may be transfered from one body (say ocean) to another (say air)
- This is called *heating* something
- Transfer occurs via collision of speedy molecules in warm body (ocean) with sluggish molecules in cold body (air) resulting in a rise of temperature of air

- Kinetic energy carried by: γ rays, X rays, UV rays, light, IR rays, microwaves, and radio waves
- Energy comes in tiny packets called photons
- Energy in each packet depends on type of radiant energy
- E.g. ☞ X-ray photons carry higher energy than UV photons which are in turn more energetic than light photons
- Light photons themselves differ in amount of energy they carry: blue photons more than yellow, yellow more than red
- Single photons are detectable by eye only under very special conditions
- Typically ☞ 60 W light bulb emits 10^{19} photons/s of visible light
- Even at a distance of 100 yards your eye would be intercepting about 5 billion of these per second
- Only at distance of about 600 miles from light bulb does your eye intercept an average of only one of these photons per second

- Newtonian idea of *force* is based on experimental observation
- Everything in universe seems to have preferred configuration
- E.g. ☞ masses attract each other
  magnets can repel or attract one another
- Concept of force is introduced to quantify tendency of objects
  to move towards their preferred configuration
- If objects accelerate very quickly towards preferred configuration
  we say that there is a big force acting on them
- If they don't move (or move at constant velocity)
  we say there is no force
- We cannot see a force
  we can only deduce its existence by observing its effect

- Forces are defined through Newton's laws of motion:
  0. *Particle* ☞ small mass at some position in space
  1. When sum of forces acting on particle is 0 ☞ its velocity is constant
  2. Sum of forces acting on particle of constant mass is equal to product of particle's mass and its acceleration ☞ $\sum \vec{F} = m \times \vec{a}$
  3. Forces exerted by two particles on each other are equal in magnitude and opposite in direction
- Newton is standard unit of force ☞ given symbol N
- 1 N ☞ force needed to accelerate 1 kg (kg = 2.2 lb) of mass at rate of 1 m/s^2
- Forces are vectors ☞ have both magnitude and direction

Example

- Gravitational force ☞ force that attracts any two objects with mass
  - Magnitude of gravitational force $= F_g = G\,M\,m/r^2$
  - Force direction ☞ along line joining objects
  - $G = 6.673 \times 10^{-11}\ \mathrm{N\,m^2/kg}$ ☞ proportionality constant
  - Near Earth's surface

$$\text{gravitational acceleration} = g = \frac{G\,M_\oplus}{R_\oplus^2} \approx 9.8\ \mathrm{m/s^2}$$

$M_\oplus = 1.3 \times 10^{25}\ \mathrm{lb}$ $\qquad$ $R_\oplus = 3,959\ \mathrm{miles}$

- Centripetal force ☞ force that keeps object moving on circular path
  - Object can move around in a circle with constant speed
    yet still be accelerating because its direction is constantly changing
  - Centripetal acceleration ☞ directed toward center of circle
  - Magnitude of centripetal acceleration = $(\text{speed})^2/\text{radius}$

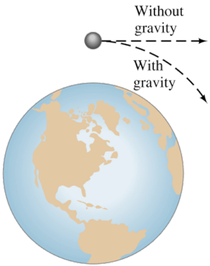
Moon continuously *falls* toward Earth due to gravity
but does not get any closer to Earth because its motion is an orbit

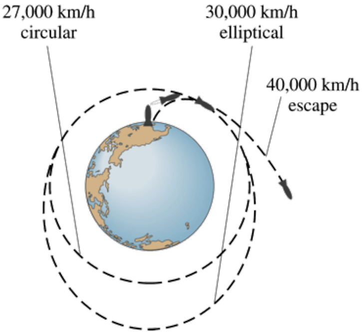
- This is energy stored whenever two masses are separated
- It is recoverable as kinetic energy when they fall together
- E.g. ☞ water to go over a waterfall (water is separated from earth)
  high jumper at top of jump
  interstellar dust before it comes together to form a star
- General expression for gravitational potential energy
  arises from gravity law and is equal to
  work done against gravity to bring mass m to given point in space

$$\text{gravitational potential energy} = U = -\frac{G\,M\,m}{r}$$

M ☞ mass of attracting body
r ☞ distance between centers

- Gravitational potential energy near planet is negative
- Negative potential energy ☞ indicative of a *bound state*
- Once mass is near large body ☞ it is trapped
  until something can provide enough energy to allow it to escape





- Zero of gravitational potential energy can be chosen at any point
  (like choice of zero of a coordinate system)

- Potential energy at height h above zero-point energy
  work which would be required to lift object
  to that height with no net change in kinetic energy

- Define ☞ work done by constant force
  product of force and distance moved in direction of force

- Near Earth's surface ☞ gravitational potential energy of mass m

$$U = \text{gravitational force} \times \text{distance} = m\, g\, h$$

h ☞ height above zero-point energy

- Sign difference in expressions of U ☞ choice of zero-point energy
- Choice is completely arbitrary ☞ important quantity
  difference in potential energy
- Summary
  - Gravitational energy is *stored* energy
  - It is not at all obvious that it is present
  - However ☞ it can be called on and used when needed
    mostly to be converted to some form of kinetic energy

- This is energy which is stored in certain (almost) unstable nuclei (such as uranium)
  and which is released when unstable nucleus is disturbed
  (in much same way as stretched rubber band which is snipped)

- This is called fission and takes place in nuclear reactors

- It is also energy which is stored when two nuclei which *want* to come together are allowed to do so
  (such as stretched rubber band which is allowed to contract)

- This is called fusion and takes place in stars

- This is repeat of nuclear story
  but with much lower energy content per gram of material
- Some chemicals release energy when they are disturbed (TNT)
  some when they combine (carbon and oxygen)
- Potential energy is said to be stored in carbon (oil, coal)
- More correctly
  it is stored in electric field between carbon and oxygen
- When C and O come together ☞ electric field gives up its energy
  in form of a photon (kinetic energy)

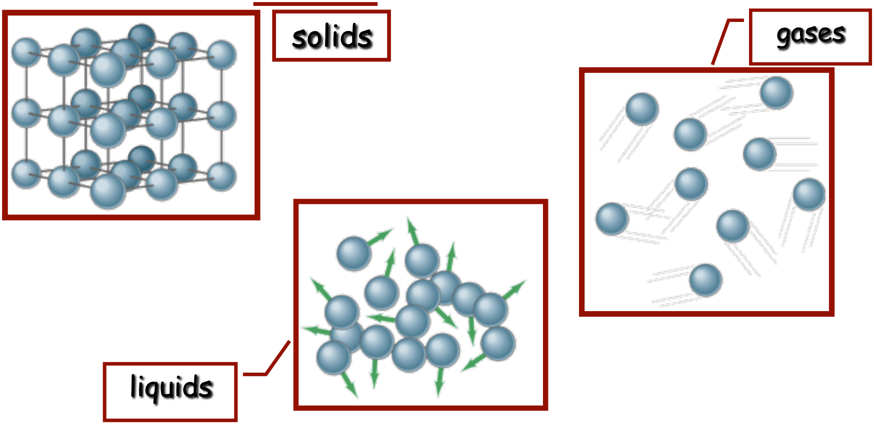
Phases of matter

Three common phases of matter are

- **solid** ☛ has definite shape and size
- **liquid** ☛ has fixed volume but can be any shape
- **gas** ☛ can be any shape and also can be easily compressed

Liquids and gases both flow and are called fluids

Arrangements of molecules



- mass ☞ measure of how much "matter" or material an object has
- weight ☞ measure of how large force of gravity is on an object

- Density of homogeneous amount of matter

$$\text{density} = \rho = \frac{M}{V}$$

- Pressure ☞ force applied perpendicular to surface of object per unit area over which that force is distributed

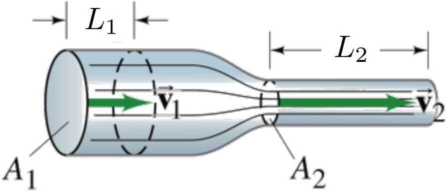
- @ depth h ☞ liquid pressure $= P = \rho g h$
  because $F_g = mg$ and $m = \rho A h$

- P depends on area A over which force F_g is distributed
- *Buoyancy* ☞ apparent loss of weight experinced by objects submerged in liquid

- Macroscopic description of buoyant force ☞ Archimedes' principle
  An immersed object is buoyed up by a force equal to the weight of fluid it displaces

- Fluid dynamics ☞ what is happening to various fluid particles
  @ particular point in space @ particular time
- Flow of fluid is said to be *steady* ☞ if at any given point
  velocity of each passing fluid particle remains constant in time
- This does not mean same velocity at different points in space
- @ some other point particle may have different velocity
  but every other particle which passes second point
  behaves exactly as previous particle passing that point
- Each particle follows smooth path
  and path of particles do not cross each other
- *Streamline* ☞ path taken by fluid particle under a steady flow

- Consider *steady flow* of fluid through enclosed pipe
  of varying cross-sectional area
- Volume $V_1 = A_1 \times L_1$ of fluid flowing through area A_1 in Δt
  must equal volume $V_2 = A_2 \times L_2$ flowing through area A_2 in Δt

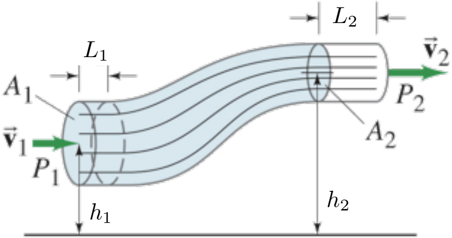


- Because no fluid flows in or out of the sides
  mass flowing past any point during Δt
  must be same as mass flowing past any other point

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

- This equation is called ☞ *continuity equation*
- If fluid is incrompressible ☞ $A_1 v_1 = A_2 v_2$

- Bernoulli's equation



$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

- Since 1 and 2 refer to any two locations along pipeline

$$P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}$$

- Conservation of energy principle appropriate for a steady flow: *Work done by pressure forces on fluid particle is equal to increase in kinetic and gravitational potential energy of particle*