Coefficient of Friction

Purpose: To measure the coefficients of static friction between a wooden block and a glass plane.

Theory: Friction is a force that resists the relative motion of two objects in contact, caused by the irregularities of the surfaces coming into contact and colliding with each other (Figure 1). Friction is a *resistive force* occurs because an object interacts with either the surface it lays upon, the medium it is contained in, or both.

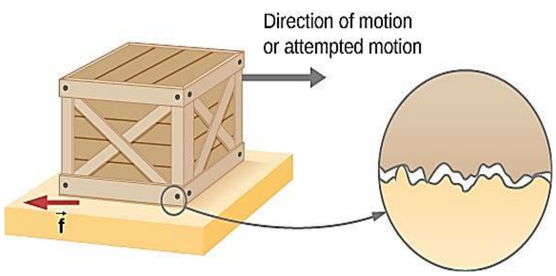

Figure 1

For most purposes, you can use the formula to calculate friction:

$$\boldsymbol{f = \mu N}$$

Where $\boldsymbol{\mu}$ is the coefficient of friction, and $\boldsymbol{N}$ is the "normal" force describes the force that the surface of an object is resting on.

For a still object on a flat surface, the friction force when the block begins to slide must *exactly* oppose the tension force due to gravity ($F = mg$).

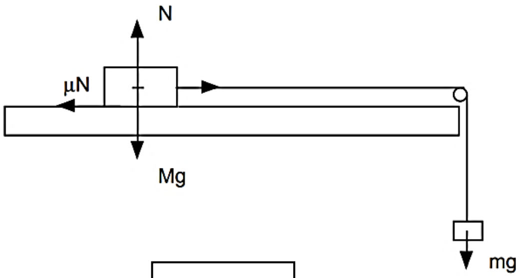

Figure 2

There are different forms of frictional forces that occur. When friction acts on an object that is at rest, we refer to the frictional force as **static friction**. An object that is in motion is subject to **kinetic** or **dynamic friction.** Fluid friction occurs between fluid layers that are moving relative to each other. This internal resistance to flow is named ***viscosity***.

Important things to know about friction:

1. Friction is always parallel to the contact surface and is in the *opposite* direction of the force causing the motion.
2. Static friction is always **greater** than kinetic friction. This is due to inertia (An object at rest tends to stay at rest while an object in motion tends to continue moving).
3. Friction increases as the force between two surfaces increases. Friction is proportional to the normal force, but *not* to the area in contact.

Static friction

When you want to push a heavy object, static friction is the force that you must overcome in order to get it moving. The magnitude of the static frictional force, $\boldsymbol{f_s}$, satisfies:

$$\boldsymbol{f_s \leq \mu_s N}$$

where $\boldsymbol{\mu_s}$ is the coefficient of static friction, a dimensionless constant that depends on the object and the surface it is laying upon.

From this equation it is clear that the maximum force of static friction, $\boldsymbol{f_{s,max}}$, that can be exerted on an object by a surface is:

$$f_{s,max} = \mu_s N.$$

Once the applied force exceeds this threshold the object will begin to move.

Equipment: Glass plane, Wooden block, Masses, Balance, Pulley and Thread.

Procedure:

1. Measure the mass of the wooden block with the balance and calculate it's weight in Newtons.
2. Tie a string to the supplied wooden block and the hanger as shown in Figure 3.

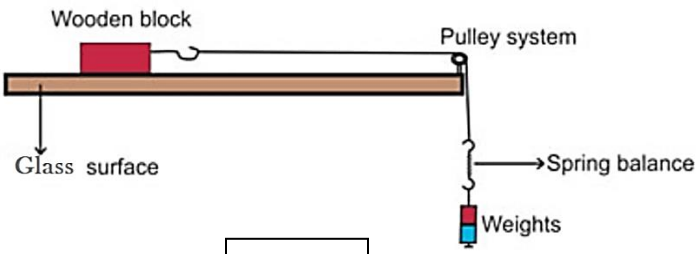

Figure 3

3. Add masses to the hanger until the block begins to slide. (Take care to gently place small increments of masses just before the block begins to move). At this point, the tension which equals mg is exactly equal to μN, the maximum frictional force.
4. Place additional masses on the block to change the total mass **M** of the block, and determine the corresponding mass **m** required to slide the block.
5. Determine the mean force. The force needed to pull the block is your frictional force (***f***) and the combined weight of the block and mass is your normal force (**N**).

M (kg)	N (N)	m (kg)	*f* (N)

6. Plot a graph with the frictional force (*f*) on the y-*axis* and the normal force (N) on the *x-axis*.

7. Make the "best fit line" to obtain the slope of this line, which is equal to the coefficient of static friction between the two surfaces (***μ***).

Question of the experiment:

Q1/ Define

- The coefficient of friction,
- Static friction,
- Viscosity

Q2/ A 7 kg box on a horizontal table is pushed by a horizontal force of 15N. If the coefficient of friction is 0.4, will the box move?

Q3/ A 400-gram package lying on a horizontal surface is attached to a horizontal string which passes over a smooth pulley. When a mass of 300 grams is attached to the other end of the string, the package is on the point of moving. Find μ, the coefficient of friction.

Hooke's Law

Purpose: Investigate the relationship between the extension (elongation) of a spring and the force applied to that spring, and determine the spring constant for an individual spring.

Theory: Hooke's law relates the force pulling or pushing on a spring (or other elastic material) to the amount of the spring stretches or compresses.

The force exerted by a spring to restore itself to its natural length is referred to as the **restoring force**. When a spring is stretched (as in this experiment) the restoring force is exerted inward; if a spring is compressed, the restoring force is exerted outward.

Mathematically, the restoring force of a spring is expressed as:

$$F = -kx$$

where F: restoring force,

k: proportionality constant, called the **spring constant**,

x: distance the spring which has been stretched or compressed.

The negative sign indicates that the restoring force acts in the direction opposite of the displacement direction.

When a mass, m, is suspended from a spring and the system is allowed to reach equilibrium, as shown in Figure 1, **Newton's Second Law** tells us that: the magnitude of the spring force equals the weight of the body, $F = mg$. Therefore, if we know the mass of a body at equilibrium, we can determine the spring force acting on the body.

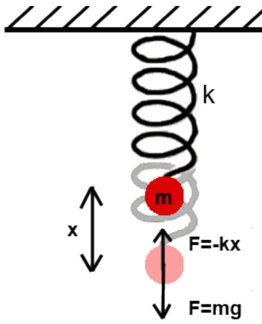

Figure 1

Depending on material, length, diameter, and number of coils, each spring has its unique spring constant. The greater the spring constant, the stiffer the spring (the more difficult it is to stretch it or compress it).

The **elastic limit** is the maximum extension to which a spring can be stretched without permanent deformation and still return to its original shape. If a spring is stretched *beyond* its elastic limit, it will *not* return to its original shape and will remain deformed.

On a force versus elongation graph, the elastic limit will show up as the point where the slope of the line changes or where the straight-line portion of the graph ends.

Commonly, a Hooke's law experiment is conducted by adding increasing masses to a spring and recording the cumulative stretch (elongation) of the spring.

Equipment:

Helical spring, Support stand and hook, Mass pan, Various slotted masses, Meter ruler.

Procedure:

1. Set up the equipment as shown in the diagram (Figure 2).

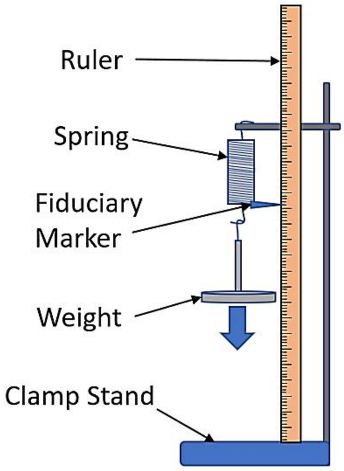

Figure 2

2. Suspend the spring from a hook and measure the original length of the spring using a ruler (calibrate the marker so that it reads *zero* when no masses are attached to the spring).
3. Attach a known weight to the spring slowly, then measure the new length of the spring which give us the extension (elongation) of the spring Δx directly (because the original length is marked on zero).
4. Continue adding weight before spring breaking or nearly stops stretching with added force.
5. Then tabulate all the data as given below.

M (kg)	F (N)	Δx (cm)	Δx (m)

6. Plot graph with the force of weight on the y-axis and the extension on the x-axis. The fact that the graph is a straight line means that the system obeys Hooke's law.

   The gradient of line of best fit will be the spring constant of the coil spring (in Newtons per meter).

Question of the experiment:

Q1/ Define:

- Hoock's law,
- Elastic region,
- Newton's second law**,**
- Spring constant
- and Restoring force.

Q2/ What is the magnitude of the force required to stretch a 20 cm-long spring, with a spring constant of 100 N/m, to a length of 21 cm?

Q3/ How much force is needed to pull a spring with a spring constant of 20 N/m a distance of 25 cm?

Physics

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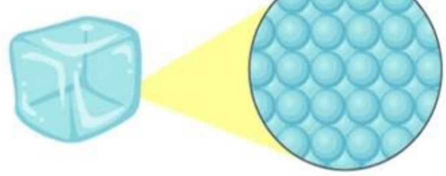
ALNOOR UNIVERSITY COLLEGE

Lecture 1

Mechanics of Elastic Solids

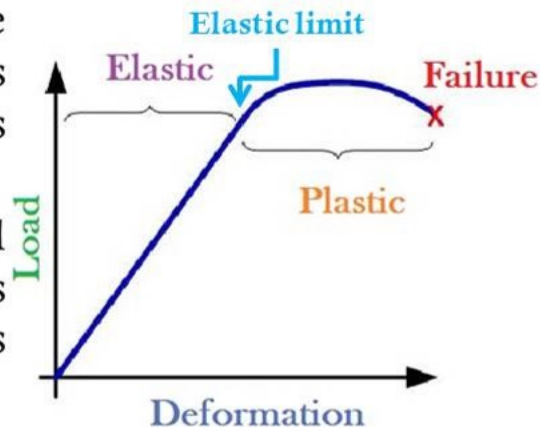
- What is a **solid** ?
  - A solid composes atoms and molecules closely arranged in a particular way.



Structure of solids

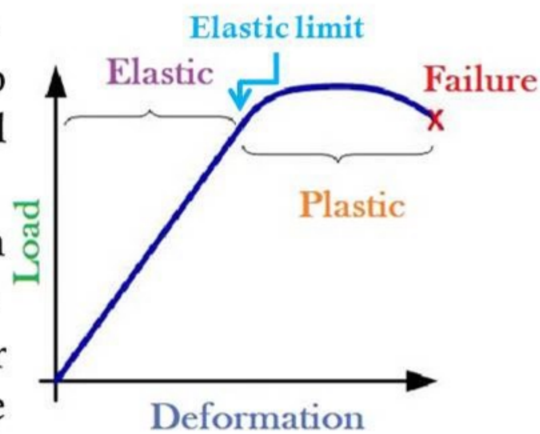
- The shape of the solid is specific due to the placement of the molecules and atoms.
- However, applying force would lead to the **displacement** of these molecules from fixed points.
- The distinguishing aspect of these material is its **elastic** and **plastic** nature.
- So there are, **Elastic behavior (response)**
  Plastic behavior (response).

- When the load (force) is firstly *applied*, a material is deformed by a change in shape or length.
- And when the load is *removed, a* material:
  - Either *return* and *goes back* to the original shape, so its called as **elastic material** which has **elastic response**.
  - Or, will *not return* to its original shape or length, so its called as **plastic material** which has **plastic response**.



- These regions are divided by the **elastic limit**.

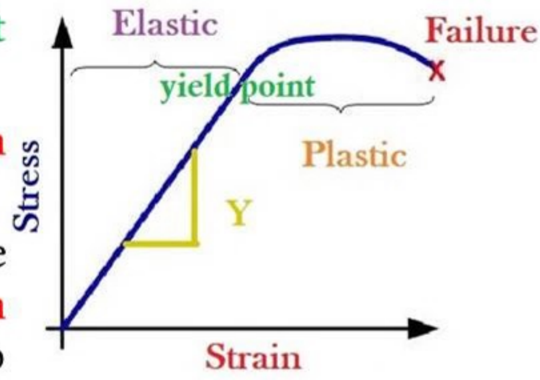
- **Elastic limit** is the point at which the material does *not* return to its original length when the load is removed.
- **Elastic deformation** occurs in the 'elastic region' of the graph.
  - The extension is proportional to the force applied to the material (straight line).



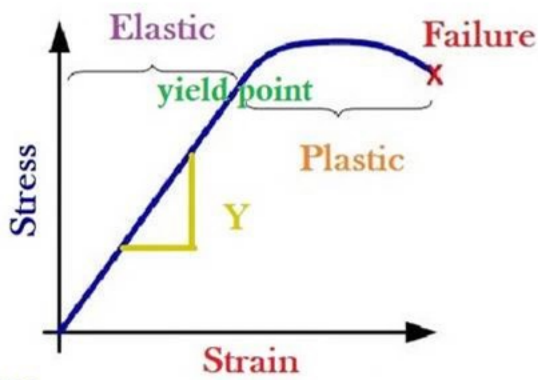
- **Plastic deformation** occurs in the 'plastic region' of the graph.
  - The extension is *no* longer proportional to the force applied to the material (graph starts to curve).

- The relationship between the load applied to a structure and the resulting deformation is called a **load-deformation curve**.
- It is generally preferable to convert:
  - load into **stress** (force per unit area),
  - deformation into **strain** (measure of deformation),

and thereby re-plot the relationship as a **stress– strain curve**, which is also divided into two regions **elastic** and **plastic** region.

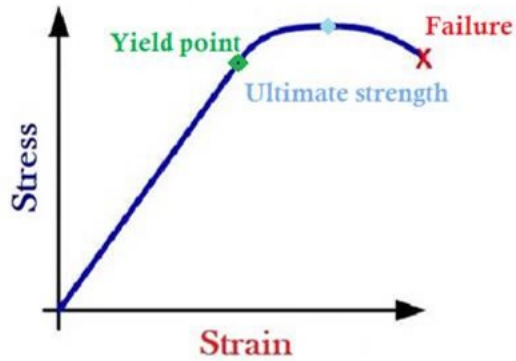


- The point where the deformation changes from being elastic to at least partially plastic is the **yield point**, which also marked by **elastic limit.**
- Within elastic range the deformation is linearly proportional to the applied force (load) [stress linearly proportional with strain], this relationship known as **Hooke's law**, which is given by: Young's modulus or the modulus of elasticity:



$$Y = \frac{\textbf{stress}}{\textbf{strain}}$$

- The **yield point** represents the value of stress above which the strain will begin to increase rapidly.
- The slight increase in stress above the yield point will result in permanent deformation this behavior is **yielding**.
- The **ultimate strength** is the maximum value of stress on the **stress**– **strain** diagram.
- **Failure** or the fracture point or the break point, which is the point at which the material fails and separates into two pieces.



- **Stress**: is the force per unit area, denoted by $\boldsymbol{\sigma}$.
  - It is the internal force, F, per unit area acting on the body:

$$\boldsymbol{\sigma} = \frac{F}{A}$$

  - The unit of stress is Nm^{-2}.
- **Strain** :is a dimensionless measure of relative deformation or percentage change in dimension (e.g. length, shape or volume), denoted by $\boldsymbol{\varepsilon}$.
  - It is the fractional change in the bone length:

$$\boldsymbol{\varepsilon} = \frac{\Delta L}{L}$$

- So Young's modulus or the modulus of elasticity:

$$Y = \frac{\sigma}{\varepsilon} = \frac{LF}{A\Delta L}$$

EXAMPLE

Q1- A load of 100 kg is suspended by a wire of length 1m and cross sectional area 0.1 cm^2. The wire is stretched by 0.2cm.

- Calculate the stress, and the strain in the wire.
- Given, g = 9.8 m/s^2.

$$\boldsymbol{\sigma} = \frac{F}{A}$$

$$= \frac{(100kg)(9.8\ m/s^2)}{0.1\times10^{-4}m^2}$$

$$= 9.8\text{x}10^7 Nm^2$$

$$\boldsymbol{\varepsilon} = \frac{\Delta L}{L}$$

$$= \frac{0.2\times10^{-2}m}{1m} = 0.2\times10^{-2}$$

Q2- A man leg can be thought of as a shaft of bone 0.3 m long. If the strain is 1.3×10^{-4} when the leg supports his weight, by how much is his leg shortened?

$$\varepsilon = \Delta L/L \ \ldots \ \ \Delta L = \varepsilon L$$

$$= 1.3\times10^{-4}\times0.3m = 3.9\times\ 10^{-5}m$$

Q3- A leg has 0.3 m shaft of bone with an average cross-sectional area of 3 cm^2 ($3\times10^{-4}\ m^2$). What is the amount of shortening when all of the body weight of 700 N is supported on this leg?

$$\Delta L = \frac{LF}{AY} = \frac{(0.3m)(7\times10^2\ N)}{(3\times10^{-4}\ m^2)(1.8\times10^{10}\ N/m^2)} = 3.9\ \times10^{-5}\ m$$

Tooth Failure

- Scientist measured the stress-strain behavior of **dentine** under compression for the premolar teeth.
- The **maximum force** measured at the occlusal surface of 1st premolar is 650 N.
  - If the **area** of contact is $\sim 10mm^2$, so the stress:

$$\sigma = \frac{F}{A} = \frac{650\ N}{10mm^2} = 65\ \frac{N}{mm^2}$$

  - If we bite a hard cherry stone or kernel of popcorn, the area of contact may be as small as $1\ mm^2$; then the compressive stress is:

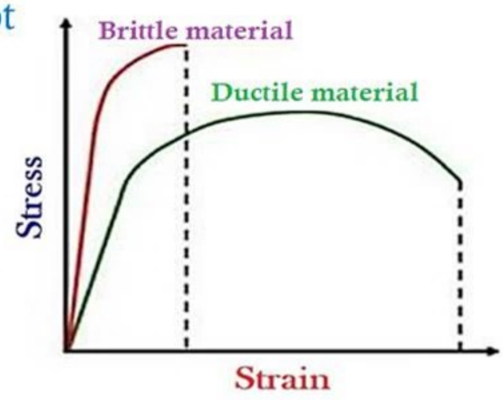
$$\sigma = \frac{F}{A} = \frac{650\ N}{1mm^2} = 650\ \frac{N}{mm^2}$$

Under these condition, the tooth would **fail**.

What Are Brittle and Ductile Meant?

- **Brittle** and **Ductile** are the two important material properties that are used to describe the physical and chemical properties of materials.
- **Brittleness** is one of the material properties where the breaking of the material will take place without any deformation.
- **Ductility** is the material property where the deformation will take place before the material gets **damaged**.
  - The materials that possess the property of brittleness are called **Brittle Materials**.
  - The materials that possess the property of ductility are called **Ductile Materials**.

- **Brittle Materials** like *Cast Iron, Ceramics, Glass, Concrete, etc.*
- **Ductile Materials** like *Aluminum, Steel, Platinum, lead,* etc.
- Brittle materials have high Young's Modulus, while ductile materials has low value.
- The brittle materials will **break** when we try to bend it, while the ductile materials cannot break even they are bent.



- The breaks in brittle materials will be occurred without any sign of cracks or breaks, while we can observe the cracks in the ductile materials before it **fails**.

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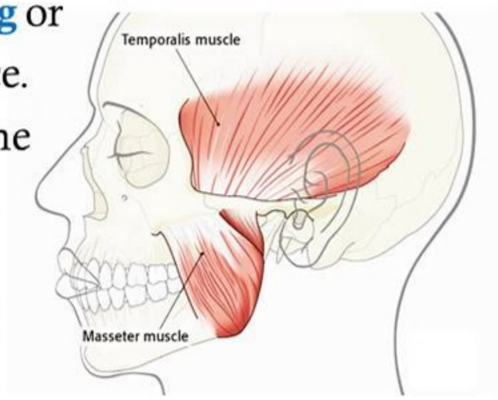
Lecture 2

Levers in Dentistry

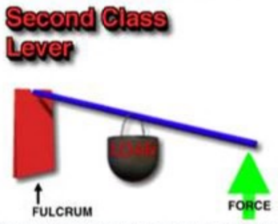
- It is obvious that different 32 permanent adult teeth have different functions.
- The incisors and canine have single **cutting** or **biting** edges.
- Behind the canine are the 1st and 2nd premolars, followed by three molars used for **chewing** or **grinding** food on occlusal surface.
- The **masseter muscle** is one of the primary muscles of mastication.
- **It's** main **functions** to provides the **masticatory forces** for biting and chewing.



Levers

- Many of the muscle and bone system of the body, as in oral cavity, act as **levers**, which consist of object resting on a fulcrum point.
- Levers has three types:

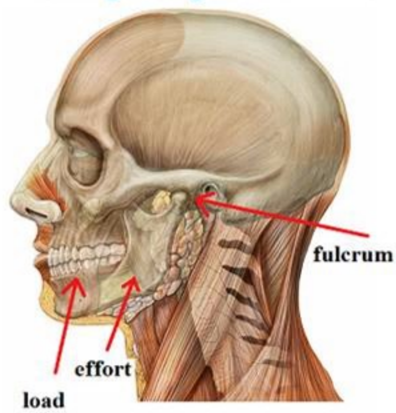
  - *First-class:* where the fulcrum is between the force and the load.
  - *Second-class*: where the load is between a fulcrum point and the force.
  - *Third-class*: where the force is between the fulcrum point and the load.



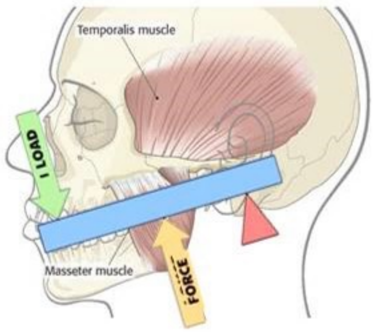
Levers in Teeth:

- The **masseter's muscle** elevate the mandible against the maxilla, so levers play an extremely important role in occlusion of our teeth in biting and chewing process.
- There are **two** different classes of lever in our jaw.
- Visualize that, **food** is the **load**, and **our jaw joint** is the **fulcrum**.

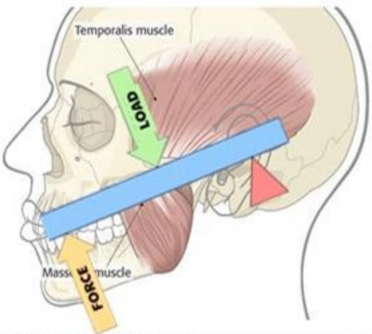
1. When you **bite** using your front teeth, such as munching a bite out of an apple, your lower jaw acts as a ***third*** *class lever*.
2. When you **crunch** on the apple with your molars, your lower jaw now acts as a ***second*** *class lever*.



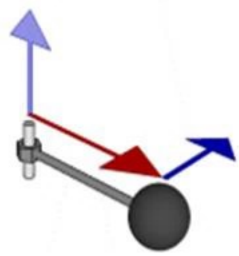
- When we **bite** an apple:
  - The food is at the front of our jaw,
  - The effort is being applied in a upward direction at the middle of the lever arm.



- When we move the food to our molars in order to **grind** it:
  - The food is approximately in the middle of the lever arm
  - The effort is being applied upward and is at the far end of the lever arm from the fulcrum.



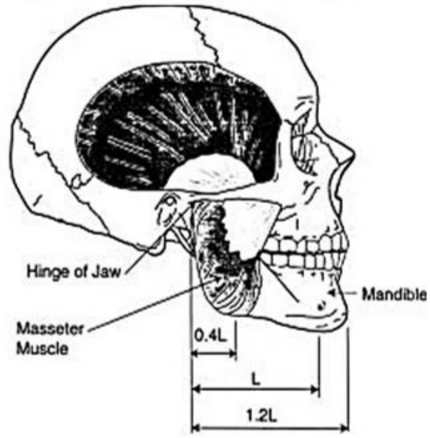
- Another aspect of physics, which is involved in chewing, is a **torque** (τ): it is a rotational force that is influenced by two factors:
  1. The length (r) of the arm that's being rotated,
  2. The strength of the force (F) that is acting on the arm from a direction that is perpendicular to the arm.



$$\vec{\tau} = \vec{F} \times \vec{r}$$

- This means that: the longer the lever arm (our lower jaw), the more torque your jaw is capable of producing, therefore, people who have a longer lower jaw **create** more torque when they chew.

- The **masticatory forces** changes at eating time to provides the main force for biting and chewing.
- It is **650N** when chewing force is supplied (using the molars)
- But during biting (using the central incisors) the net force would be **540N**.

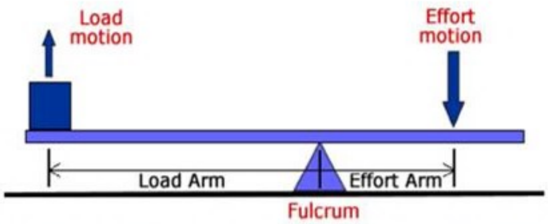


- **L**: the distance from **1st premolar** to hinge of the jaw.
- **0.4 L**: the distance from **the masseter muscle** to the hinge.
- **1. 2L**: the distance from the **central incisor** to the hinge.
- ✓ L ~ 6.5 cm for *women*, and ~8 cm for *men*.

The Mechanical Advantage of Lever

- Each lever has its own uses and advantages.
- The efficiency of the lever is called **Mechanical Advantage** (**MA**).
- It is a ratio that shows how much easier a simple machine has made an operation.
- The greater **MA**, the less effort required.
- **MA** of levers may be determined by:

$$\textbf{Mechanical Advantage} = \frac{\text{Load}}{\text{Effort}}$$



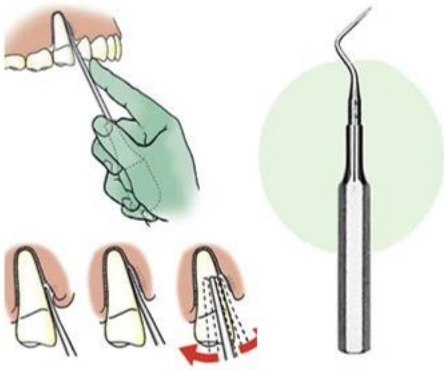
or

$$= \frac{\text{Length of effort arm}}{\text{Length of load arm}}$$

Levers in Dental Instruments

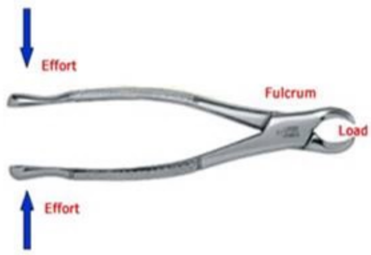
- Dentists have a variety of tools, that are used to apply pressure to teeth. Some of them are:

1. **Extraction forceps**: is a dental instrument look like specialized pliers. Used to grasp and manipulate teeth during the extraction process.
2. **Dental Elevator**: is a specialized lever. Used to loosen teeth before application of forceps extraction when teeth cannot be reached with forceps.

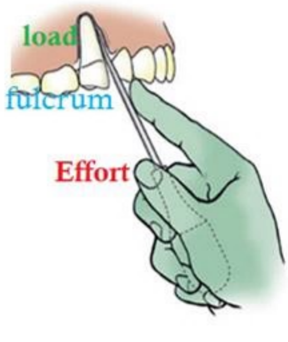


The Mechanical Principle of Levers

- When levers used with **forceps**:
  - The hinge of the forceps acts as the fulcrum while the arms of the forceps act as each component of a lever (effort).
  - To exert the most force, the grip should be farther from the fulcrum or hinge.

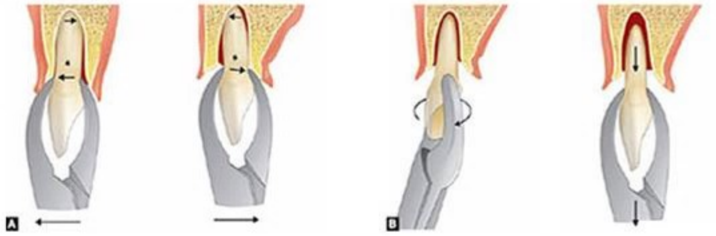


- When levers used with **elevators**:
  - The handle of the elevator is the effort, while the tip of the blade is the working end applies the load to the tooth.



How are They Used ?

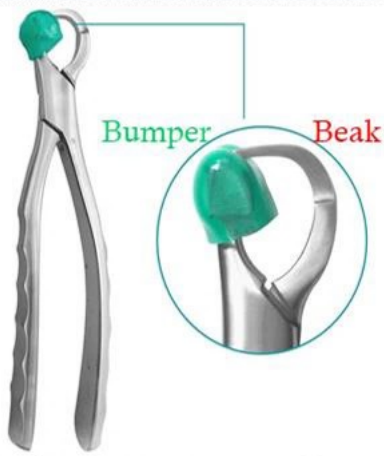
1. In **forceps:** a dentist will grasp a tooth by slowly rock it back and forth (**rocking force**). Then make **rotation force** to rotate it. Finally, the socket will use to remove the tooth.



2. In **elevators:** the lever is the *first class*, so the handle on one side of fulcrum must be longer than the load arm on opposite side to get maximum **MA** of extraction.

3. **Physics Forceps** is a simple, and unconventional method of extracting teeth.

- It operates as an **elevator** rather than forceps, using *first-class lever*.
- One handle is connected to a "**bumper**" which acts as the fulcrum, that is placed deep in the **vestibule**.



- The other handle is connected to the "beak" of the lever arm.
- **It's** technique significantly reduces time and stress for your patients and for yourself.

Physics

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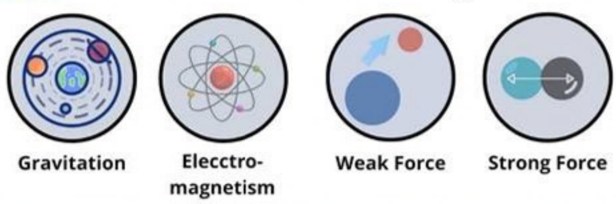
Lecture 3

Forces

- **Force** is any action that tends to maintain or alter the motion of a body or to distort it.
- The muscular forces, for example, cause the blood to circulate, and the lungs to take in air.
- A **force** has both magnitude and direction, making it a vector quantity, and illustrated by arrows.
- It is measured in **newton** (**N**), and represented by the symbol **F**.
- There are **four** fundamental forces, from weakest to strongest:



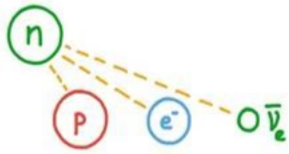
1. Gravitational force

- It is weak force but very long-ranged.
- It is always attractive.
- The law of universal gravitation states that:

"there is a force of attraction between any two objects",

"Our weigh is due to the attraction between the earth and our bodies".

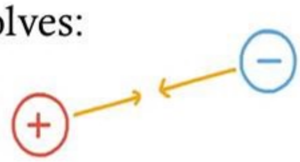
2. Weak nuclear force:



- It is responsible for radioactive decay.
- It is involved with electron (beta) decay from the nucleus.
- It has a very short range and it is very weak.

3. Electrical force

- It is long-ranged but much weaker than the strong force.
- It causes electric and magnetic effects, involves:



1. **attractive** and **repulsive** forces between static electrical charges,
2. **magnetic** forces produced by moving electrical charges.

4. Strong nuclear force

- It is very strong but very short-ranged.
- It is much larger than the other, and acts as the "glue" to hold the nucleus together.

Forces on the Body

- The are two types of problems involving forces:
  - ✓ those where the body is in *equilibrium* (**statics**),
  - ✓ those where the body is *accelerated* (**dynamic**).

1- Statics Force

- When objects are statics they are in a state of **equilibrium** { remains in its state of rest or motion }.
  - "the sum of the forces in any direction is equal to zero"&
  - "the sum of the torque about any axis equal to zero".
- In order for a two force member to be in equilibrium, the *two forces* must:

(a) have the same magnitude.

(b) act along the same line. (c) be opposite in sense.

2- Dynamics Force

- **Dynamics** is the study of the forces that cause objects and systems to **move**.
- The study of dynamics falls under two categories:

1. Linear dynamics pertains to objects moving in a line.
2. Rotational dynamics pertains to objects that are rotating or moving in a curved path.

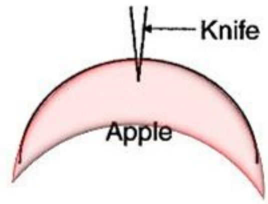
- If a net force acts on an object, it will cause an **acceleration** or **deceleration** of that object. The amount of acceleration or deceleration needed to move an object known as Dynamics Force.

$$\boldsymbol{F} = \boldsymbol{ma} = \frac{\boldsymbol{m\Delta v}}{\boldsymbol{\Delta t}}$$

where $\boldsymbol{a}$ is the acceleration, $\boldsymbol{m}$ is the mass, and $\boldsymbol{v}$ is the velocity.

Biting Process

- The **incisors** act like knives in the biting process. You can imagine that by visualize a dull knife on an apple :

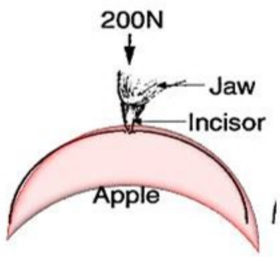


(a)

- The teeth behave like the knife, and when the incisors first make contact with the apple, the stress ($\sigma = \frac{F}{A}$) is very **large** because of:
  - ✓ the ***large*** applied force (assume 200 N);
  - ✓ the ***small*** area of the edge of the incisor teeth (perhaps 1 mm^2).
- This applied force leads to a stress of:

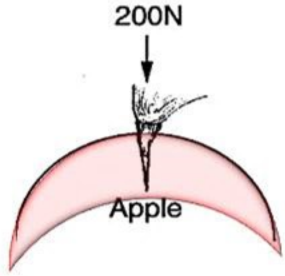
$$\sigma = 200N/mm^2$$

which is sufficiently large to rupture the apple.

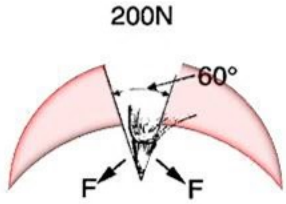


(b)

- The apple's skin has been ruptured, then the front and back surfaces of the teeth make contact with the interior of the apple.
- The angle of the front incisors ~60°, where the force of 200N is still applied by the jaw on the front teeth.
- The downward force is **balanced** by the two components of force **F** normal to the front and back surfaces of the incisors.
- These two forces can be large and push apart the two sides of the apple being bitten, causing the crack to spread.



(c)



(d)

Frictional Force

- **Friction** is a force that always acts to **resist** the motion of one object on another.
- We distinguish **two** types of friction:
  - **Static** friction, between two surfaces at rest.
  - **Kinetic** friction, between two surfaces one moves against the other.
- The maximum force of friction f is : $f = \mu N$

where **N**: is a normal force,

μ: is the coefficient of friction between the two surfaces.

- The value of μ depends upon the two materials in contact, and independent of the surface area.
- Frictional forces between **fluids** known as **viscous forces**.

Retarding Force

- A body moving through a liquid or gas is retarded by the force of **viscosity** exerted on it by the fluid.
- The **viscosity** of a fluid is a measure of the **internal friction** opposing the deformation or flow of the fluid.
- When a solid sphere is moving in a liquid, a viscous **drag force** will be exerted on the sphere.
- This force has a simple velocity dependence,

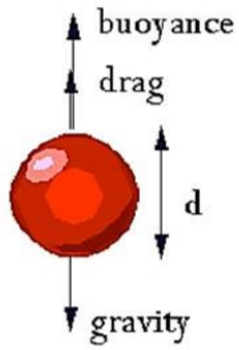
and given by **Stocke's law**:

$$F_d = 6\,\pi\, r\, \eta\, v$$

where η viscosity of the fluid,

r the radius of the sphere

and v the sphere velocity.



- When a steel ball is dropped into a fluid sample the **gravitational force** on the ball ($F_w = mg$) is **larger** than the **buoyant** force F_b.
- The net driving force F on the ball is:

$$F = F_w - F_b = (\sigma - \rho)\left(\frac{4}{3}\pi r^3\right) g$$

- When $F = F_d$,
  - the ball stops accelerating
  - and falls with a **constant** speed, which is called the **terminal speed**.
- A related medical test is the determination of the hematocrit, the percent of red blood cells in the blood.

- **Stocke's law** utilized in test that can reveal inflammatory activity in your body, this test known as **Sed Rate**, or **Erythrocyte Sedimentation Rate** (**ESR**).
- When your blood is placed in a tall, thin tube, red blood cells gradually settle to the bottom.
- Inflammation can cause the cells to clump, and these clumps are **denser** than individual cells, so they settle to the bottom more quickly.
- High rate of settlement indicating high inflammation.

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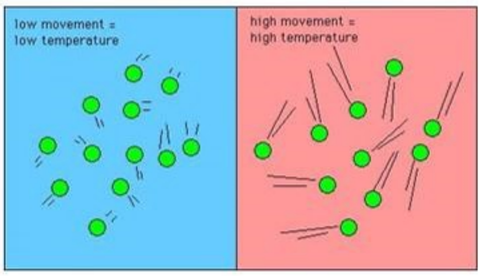
Lecture 4

Heat and the First Law of Thermodynamics

Physical Basis of Heat and Temperature

- Matter is composed of molecules that are in motion, in a **gas** or **liquid** or even in a **solid**.
- This movement means that:

"they have **kinetic energy** (**K.E.**)" which related to the temperature by direct proportional.



- So to **increase** the temperature of a gas it is necessary to **increase** the **K.E.** of its molecules.
- The energy that transferred causing the temperature rise is called **heat**.
- It is the total energy of molecular motion in a substance.

Temperature Scales

1. **Fahrenheit (^{0}F) scale**:

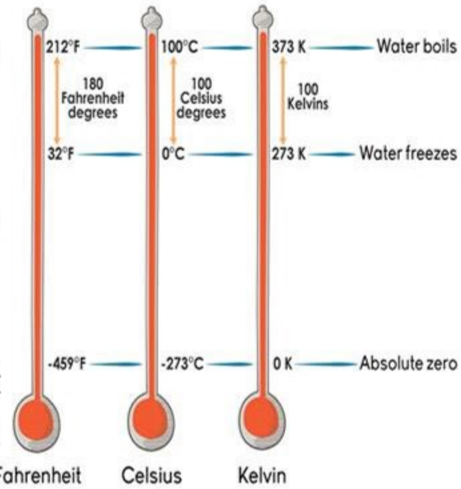
Water freezes at 32^{0}F and boils at 212^{0}F, normal body temperature ~98.6^{0}F.

2. **Celsius (^{0}C) scale**:

Water freezes at 0^{0}C and boils at 100^{0}C, normal body temperature ~37^{0}C.

3. **Kelvin (^{0}K) scale:**

Water freezes at 273.15^{0}K and boils at 373.15 ^{0}K , normal body temperature ~310 ^{0}k.



- Temperature conversion formulas are:

$$T_K = T_C + 273.15 \qquad T_C = \frac{5}{9}(T_F - 32) \qquad T_F = \frac{9}{5}T_C + 32$$

Examples:

Q1- Convert 122°F = … °C to centigrade

$$T_C = \frac{5}{9}(T_F - 32)$$

$$= \frac{5}{9}(\mathbf{122} - 32) = \frac{5}{9}(90) = 50°C$$

Q2- Convert 16°C into Kelvin.

$$T_K = T_C + 273.15$$

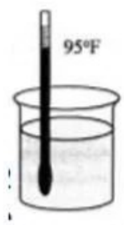
$$= \mathbf{16} + 273.15 = 289.15°K$$

Q3- Convert 100 degrees Fahrenheit to Kelvin.

$$T_K = T_C + 273.15$$

$$= \frac{5}{9}(T_F - 32) + 273.15$$

$$= (100 - 32) \times 5/9 + 273.15 = 310.93° \text{ K}$$



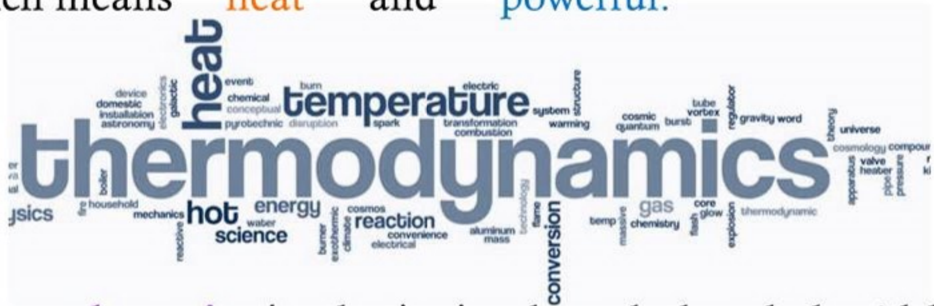
H.W: What is the liquid temperature in Celsius scale.

Thermodynamics

- **Thermodynamics** can be *defined* as: the study of energy, energy transformations and its relation to matter.
- "**Thermodynamics**" is derived from two Greek words:

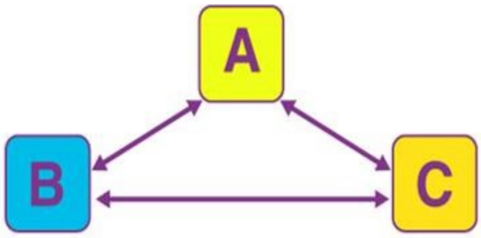
  "**thermes**" and "**dynamikos**"

  which means heat and powerful.



- **Thermodynamics** in physics is a branch that *deals with* heat, work and temperature, and their relation to energy, radiation and physical properties of matter.

- **Thermodynamics** studies **conversion of energy** from one form to the other (chemical to heat, heat to mechanical,….. est.).
- The field of study of thermodynamics is based on **three laws** of thermodynamics and **Zeroth's law**.
- **Zeroth's Law of Thermodynamics** states that if two bodies are in thermal equilibrium with third body, then they are in thermal equilibrium with each other.
  - *For example*, if temperature of **A** is equal to temperature of **C**,
  - and temperature of **B** is also equal to temperature of **C**,
  - then temperature of **A** is equal to that of **B**.



The First Law of Thermodynamics

- The **1st law of thermodynamics** is one of the three fundamental laws of thermodynamics.
- It is derived from the **conservation of energy**, and states that:
  - energy can neither be created nor be destroyed,
  - it can *only* be transferred from one form to another.
- It states that:

the change in **thermal energy** (ΔU) (change in internal energy) of an object	=	the heat (**Q**) that is added to the object	−	the **work** (**W**) done by the object.

$$\Delta U \ (E2 - E1) = Q - W$$

- **Internal Energy (U)** of a system on a smaller scale can be considered as the stored sum of the kinetic and potential energy of its atoms and molecules.
  - **U** can be **positive** when heat is added to the system and/or work is done on the system.
  - **U** can be **negative** when heat is removed from the system and/or work is done by the system on its surroundings.
- **Heat (Q)** is the energy that is transferred by molecular motion and collisions due to a temperature difference.
  - **Q** that enters a system can be considered to be **positive**,
  - while **Q** exiting a system is **negative**.

- **The work (W)** of a system is the energy that is transferred from one system to another or to its surroundings. This is a general form of mechanical work.
  - **W** is **negative** when energy is lost from the system and consumed by an external system or the surroundings.
  - **W** is **positive** when energy is added to the system and lost from an external system or the surroundings.

Examples	System is positive	System is negative
A **steam engine** produces work.	energy is added to surroundings from the engine.	energy is lost from the engine to the surroundings
Refrigerators consume work.	energy is added to refrigerators from the environment.	energy is lost from the environment

Examples:

Q1- Calculate the change in the system's internal energy if 3000 J of heat is added to a system and a work of 2500 J is done by the system.

$$\Delta U = Q - W$$
$$= 3000 - 2500 = 500 J$$

Q2- What is the change in the internal energy of the system if 2000 J of heat leaves the system and 3000 J of work is done on the system?

$$\Delta U = Q - W$$
$$= -2000 - (-3000) = -1000 J$$

Note : Q is +ve if the heat added to the system, -ve if heat leaves the system
W is +ve if work is done by the system, -ve if work is done on the system

Q4- Compute the internal energy change for the two processes of an ideal gas:

(a) 1500 J of heat are added to the gas and the gas does no work and no work is done on the gas.

$$\Delta U = Q - W$$
$$= 1500J - 0 = 1500J$$

(b) 1500 J of work are done on the gas and the gas does no work and no heat is added or taken away from the gas.

$$\Delta U = Q - W$$
$$= 0 - (-1500J) = 1500J$$

Q5- A gas in a closed container is heated with 50 J of energy, causing the lid of the container to rise. If the change in energy of the system is 30 J, how much work was done by the system?

$$\Delta U = Q - W$$
$$30\ J = 50\ J - W$$
$$-20\ J = -W$$
$$20\ J = W$$

- **H.W.** What is the change in the internal energy of the system if 2000 J of heat is added to the system and 2500 J of work is done on the system?

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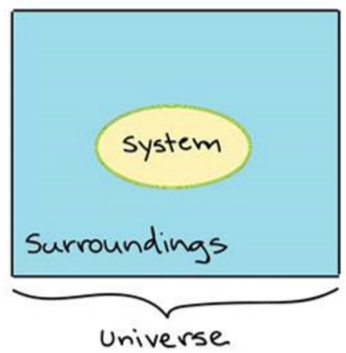
Lecture 5

Thermodynamics 2

Thermodynamic Systems

- A **system** is defined as a quantity of matter or a region in space chosen for study.
- The mass or region outside the system is called the **surroundings**.
- The envelop which is covered the system is known as **boundary** of system. It is the real or imaginary surface that separates the system from its surroundings. It has zero thickness, no mass, and no volume.



- **Universe**: is the combination of thermodynamic system:

Universe = **System** + **Boundary** + Surroundings

Types of Thermodynamic Systems

- There are three types of systems that are frequently used to describe *thermodynamic properties*:

1. **Open system**: can exchange both energy and matter with its surrounding
2. **Closed system**: can exchange energy but not matter with its surrounding
3. **Isolated system**: that cant exchange neither matter nor energy.

Conservation of Energy

- The total energy is neither increased nor decreased in any process.
- Energy can be transformed from *one form to another*, and transferred from *one object to another*, but the total amount remains **constant**.
- So in an isolated system such as the universe, if there is a loss of energy in some part of it, there must be a gain of an equal amount of energy in some other part of the universe.
- When a **system** and its **surroundings** undergo a transition from an *initial* state to a *final* state, the change in energy is zero,

$$\Delta E = \Delta E_{system} + \Delta E_{surroundings} = 0$$

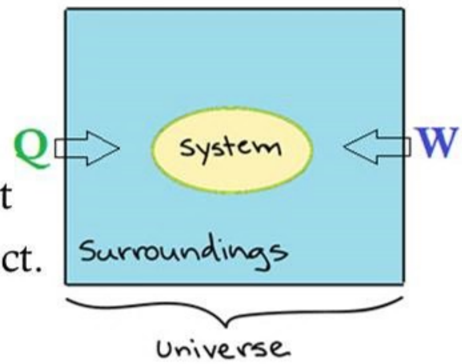
Thermodynamic Laws

- **1st Law of Thermodynamics**: Energy can neither be created nor be destroyed, it can only be transferred from one form to another.
- **2nd Law of Thermodynamics:** The entropy of any isolated system always increases.
- **3rd Law of Thermodynamics:** The entropy of a system approaches a constant value as the temperature approaches absolute zero.

note

- ✓ **Entropy** is the measure of the number of possible arrangements the atoms in a system can have.
- ✓ **Enthalpy** is the measurement of energy in a thermodynamic system.

- For thermodynamics, **the 1st law** is an expression of the principle of conservation of energy.
- It states that the change in **thermal energy** (ΔU) of an object is equal to the heat (**Q**) that is added to the object minus the **work** (**W**) done by the object.



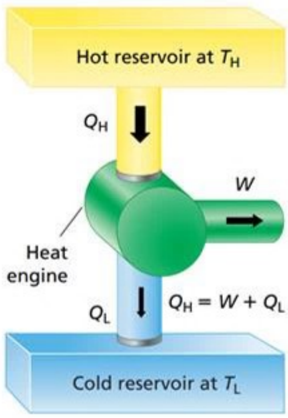
$$\Delta U = Q - W$$

- Because **Universe** = **System** + ~~**Boundary**~~ + **Surroundings**, and the **1st law** states that the energy of the universe is a constant, so : $\Delta E_{Universe} = 0$

$$\Delta E_{System} = -\Delta E_{Surroundings}$$

Example: Heat engines

- A device that is able to continuously convert thermal energy to mechanical energy. It requires :
  - a high-temperature source from which thermal energy can be removed;
  - a low-temperature receptacle, called a sink, into which thermal energy can be delivered;



  - and a way to convert the thermal energy into work.
  - Q_H is the input heat.
  - Where $Q = Q_H - Q_L$, and $\Delta U = Q - W = 0$, Thus, the work done by the engine is $W = Q_H - Q_L$.

Example:

Q- A gas in a closed container is heated with 50 J of energy, causing the lid of the container to rise. If the change in energy of the system is 30 J, how much work was done by the system?

For this problem, use the first law of thermodynamics:

$$\Delta U = Q - W$$

We are given the total change in energy and the original amount of heat added.

Using these values, we can get:

$$30\ J = 50\ J - W$$

$$-20\ J = -W$$

$$20\ J = W$$

- Our "energy accounting" has two types:
- **Kinetic Energy:** The energy that an object possesses because its moving. It is defined as:

$$\mathbf{KE} = \frac{1}{2} M V^2$$

where M: is the mass of the object,

V : is the magnitude of its velocity.

2. **Potential Energy:** The energy due to an object's position (stored energy) known as potential energy. It is defined as:

$$\mathbf{PE} = m\boldsymbol{g}z$$

where m: is the mass,

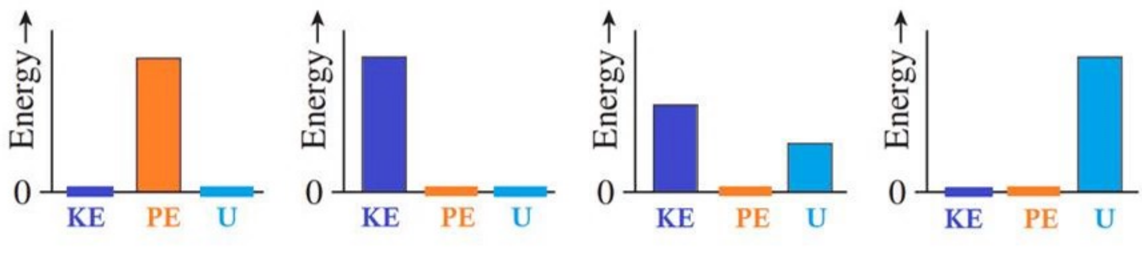
z: is the elevation,

$\boldsymbol{g}$: is the gravitational acceleration.

- Accounting for internal energy leads to a broader statement of energy conservation.

$$\Delta\mathbf{KE} + \Delta\mathbf{PE} + \Delta\mathbf{U} = \mathbf{0}$$

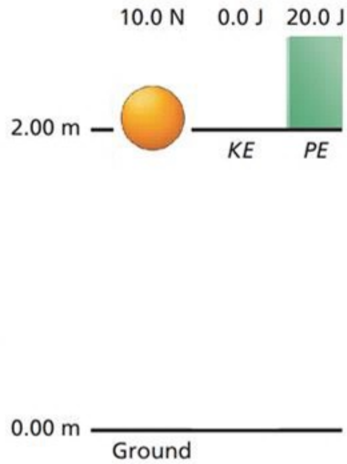
This equation shows that the sum of the kinetic, potential, and internal energy of an isolated system doesn't change even though energy may be converted among these three different forms.



- In any given system, if no other forms of energy are present, so the energy is mechanical energy:

$$E = KE + PE$$

- Imagine a system consisting of a 10N ball and Earth.
- Suppose the ball is released from 2m above the ground. Because the ball is not yet moving, it has no kinetic energy.



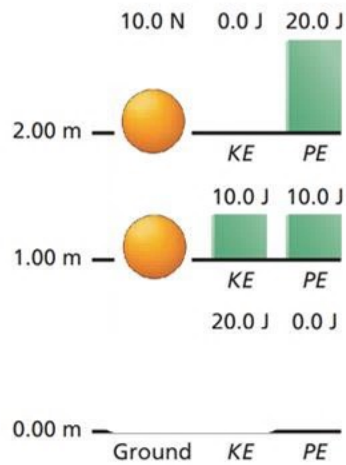
$$PE = mgz = 10\ N \times 2\ m = 20\ J$$

- As the ball falls, it loses PE and gains KE. When the ball is 1m above Earth's surface:

$$PE = 10\ N \times 1\ m = 10\ J$$

What is the ball's kinetic energy when it is at a height of 1m?

- The system consisting of the ball and Earth is closed and isolated because no external forces are acting upon it. Hence, the total energy of the system (E) remains constant at 20 J.



$$E = KE + PE \quad \text{so} \quad KE = E - PE$$

$$\therefore KE = 10\ J$$

- When the ball reaches ground level:

$$PE = 0$$

$$KE = 20\ J$$

Check the velocity of ball .

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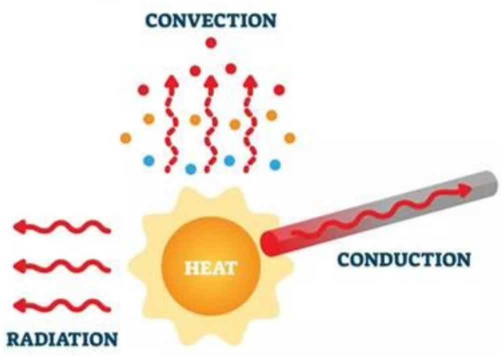
Lecture 6

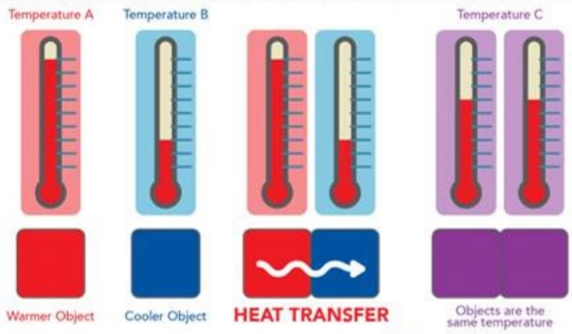
Thermodynamics of Heat Transfer

Introduction

- Any matter which is made up of atoms and molecules has the ability to transfer heat.
- According to thermodynamic systems, **heat transfer** is defined as "The movement of heat across the border of the system due to a difference in temperature between the system and its surroundings."
- Heat transfer is the process of the movement of **energy** due to a temperature difference.
- Heat may be transferred by **conduction**, **convection**, or **radiation**.



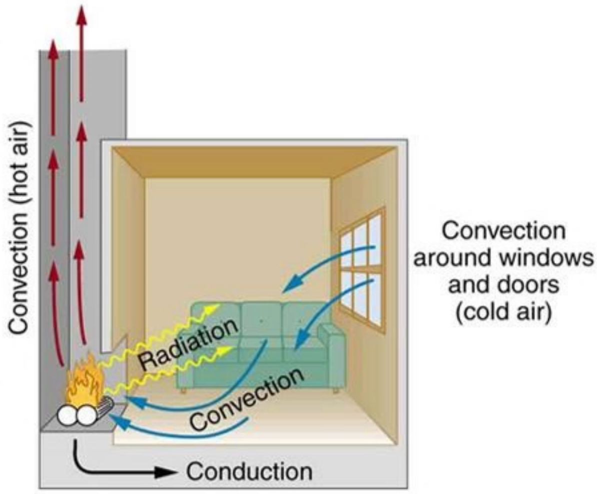
- **Heat** is described as the **energy** that always flows from the hotter object or warm object to the cooler object.



- Heat caused rising the temperature of cold one until equilibrium is reached and the bodies reach thermal equilibrium (they are at the same temperature).
  - An object that is **hotter** than its surroundings *radiates* more energy than it absorbs,
  - whereas an object that is **cooler** than its surroundings *absorbs* more energy than it radiates.

Heat Transfer Methods

1. **Conduction**: The process of transmission of energy from one particle of the medium to another with the particles being in direct contact with each other.
2. **Convection**: The movement of fluid molecules from higher temperature regions to lower temperature regions.
3. **Radiation** is generated by the emission of electromagnetic waves. These waves carry away the energy from the emitting body.



Thermodynamic Properties

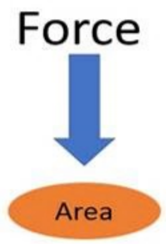
- Any characteristic of a system is called a property and, in general, thermodynamic properties can be divided into:

1. **Extensive properties**: property that *dependent* upon the amount of mass present or upon the size or extent of a system. For example: **mass**, volume.
2. **Intensive property**: property that ***in**dependent* of the amount of mass and may vary from place to place within the system at any moment. For example: temperature, **pressure**.
3. **Specific properties** of material *are derived* from other intensive and extensive properties of that material. For example, the **density** of water:

$$\rho = \frac{m}{V}$$

Pressure

- **Pressure** on the boundaries of a substance is caused by the **collisions** of the molecules of the substance with the boundaries of the system.
- As molecules hit the walls, they exert forces that try to push the walls outward.
- The forces resulting from all of these collisions cause the **pressure** exerted by a system on its surroundings.
- **Pressure** is a measure of the **force (F)** exerted per unit **area (A)** on the boundaries of a substance.



$$P = F/A$$

- The SI unit of pressure is the **pascal**.

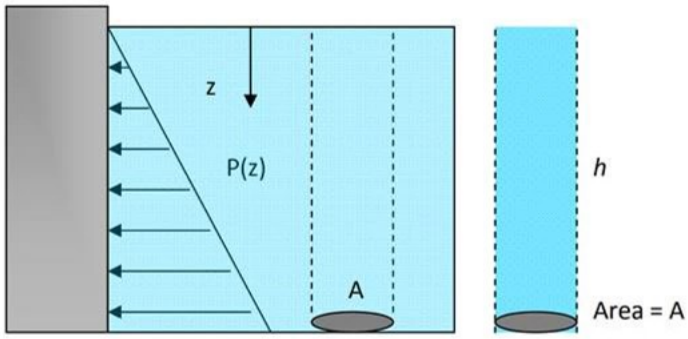
$$1\,\text{pascal} = 1\ N/m^2$$

- In fluids, gases and liquids, we speak of **pressure**;
- In solids this is **stress**.
- For a fluid at rest, the pressure at a given point is the same in all directions.

$$P = \frac{\text{Weight of liquid}}{\text{Area}}$$

$$P = \frac{mg}{A} = \frac{\rho Ahg}{A}$$

$$P = \boldsymbol{\rho} gh$$



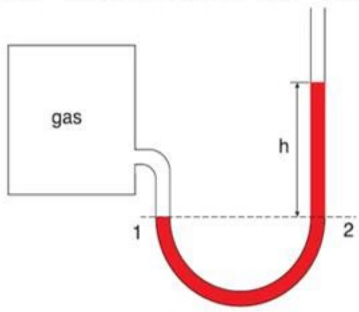
- Pressure of a fluid at rest increases with depth (due to added weight), but constant in horizontal planes.

- In thermodynamics calculations, always use **absolute pressure,** which is the actual pressure at a given position.
- An instrument that measures pressure by this method is called **Manometer**: A common type is a U-shape tube containing a fluid that is connected to the pressure to be measured.
- The levels in the arms change until the difference in the levels is equal to the pressure.

$$\boldsymbol{P} = \boldsymbol{P_o} + \rho gh$$

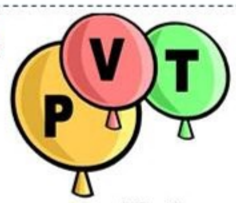
where $\boldsymbol{P_o}$: is the atmospheric pressure.

- If the ($P < P_o$) called negative pressure,
- If the ($P > P_o$) called positive pressure.



Ideal Gas Law

- The relationship between the **pressure**, **volume**, and **temperature** for an ideal gas is given by the **ideal gas law**.



- The product of pressure and volume (**PV**) is a *constant* if the gas is kept at isothermal conditions.
- The value of the *constant* is **nRT**, so the ideal gas law

$$PV = nRT$$

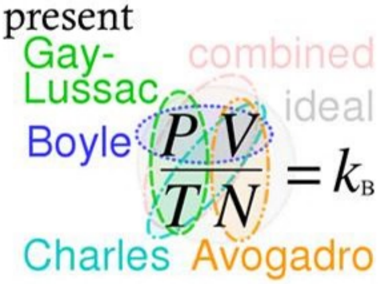
where **n** is the number of moles of gas present

R is the ideal gas constant.

= 8.31 J/mole.K

= 0.082 L.atm/mole.K

T is the temperature of the gas



- **Boyle's law**: The volume **V** of a given mass of a gas is inversely related to pressure when the temperature is constant.

$$V = \frac{nRT}{P} = \frac{\text{constatnt}}{P}$$

$$V \ \alpha \ \frac{1}{P}$$

So $$P_1V_1 = P_2V_2$$

- **Charles's law**: The volume **V** of a given mass of a gas, at constant pressure **P** , is directly proportional to it's temperature **T**.

$$V = \text{constatnt } T$$

$$V \propto T$$

So $$V_1/T_1 = V_2/T_2$$

- **Avogadro's law**: States that the volume occupied by an ideal gas is directly proportional to the number of molecules of the gas present in the container.
- The relation is given by:

$$\mathbf{V} = \text{constatnt}\ \mathbf{n}$$

So $$\mathbf{V}_1/\mathbf{n}_1 = \mathbf{V}_2/\mathbf{n}_2$$

- **Gay-Lussac's law**: It states that , for a given mass and constant volume of an ideal gas, the pressure exerted on the sides of its container is directly proportional to its absolute temperature.

$$\mathbf{V} = \text{constatnt}\ \mathbf{T}$$

So $$\mathbf{P}_1/\mathbf{T}_1 = \mathbf{P}_2/\mathbf{T}_2$$

Example

1. A 12 g sample of gas occupies 19.2 L at STP. What is the molecular weight of this gas?

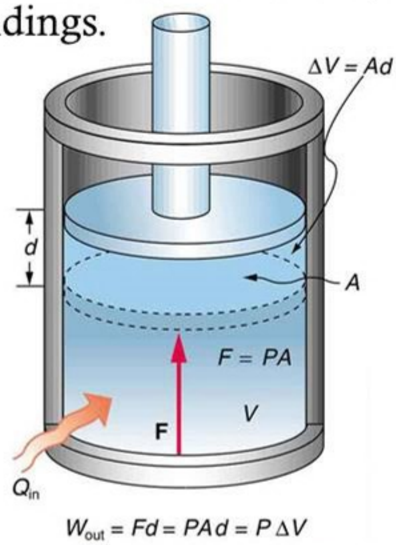
$$PV = nRT$$
$$(1\ \text{atm})\ (19.2\ \text{L}) = (n)\ (0.082)\ (273\ \text{K})$$
$$n = 0.8570518\ \text{mol}$$

2. What is the temperature of One mole of CH4 gas that occupies 20L at 1atm pressure in Kelvin?

$$PV = nRT$$
$$T = PV/nR$$
$$T = 1\text{atm}\times 20\text{L}/1\text{mol}\times 0.082$$
$$T = 244\text{K}$$

Work

- In thermodynamics, **work** performed by a system is energy transferred by the system to its surroundings, by a mechanism through which the system can spontaneously exert macroscopic forces on its surroundings.



$$W = F \cdot d$$

where: **W**: is the work,

F: is the force,

d: is the displacement.

- Because $P = F/A$ >> $F = PA$

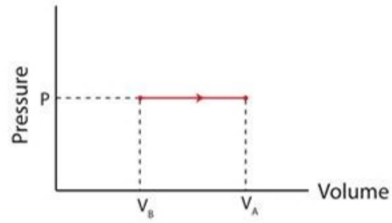
So:

$$W = PA\,d$$

$$W = P\,\Delta V$$

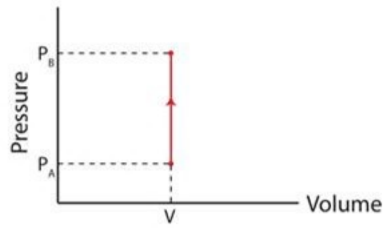
Thermodynamics Processes

- A process in which a gas does work on its environment at *constant* **pressure** is called an **isobaric process**,

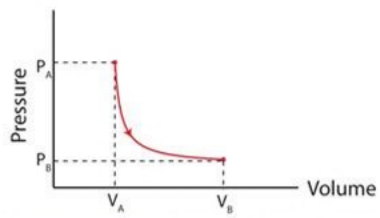


- While one in which **volume** is kept

constant is called an **isochoric process**.



- Where **Isothermal Processes** is a change of a thermodynamic system, in which the **temperature** remains constant.



Simple Pendulum

Purpose: To find the gravitational acceleration due to the gravity of a swinging object about a point.

Theory: A simple pendulum is defined to have a point mass (the pendulum bob) suspended by a massless (light) string from some point about which it is allowed to swing back and forth in a place. A simple pendulum can be used to perform the *simple harmonic motion* (*SHM*).

In Figure 1 we see that a simple pendulum has a small-diameter bob and a string that has small mass ***m*,** which is strong enough not to stretch appreciably. The linear displacement from equilibrium is $\boldsymbol{s}$ (the length of the arc).

The weight $\boldsymbol{mg}$ has two components: $\boldsymbol{mg\ cos\theta}$ along the string, and $\boldsymbol{mg\ sin\theta}$ tangent to the arc. Therefore the net force on the bob is:

- Tangent to the arc and equals $-\boldsymbol{mg}\ \mathbf{sin}\boldsymbol{\theta}$, which result in a net force toward the equilibrium position, known as a **restoring force**.
- While **Tension** ($\boldsymbol{F_T}$) in the string exactly cancels the component $\boldsymbol{mg}\ \mathbf{cos}\boldsymbol{\theta}$ parallel to the string.

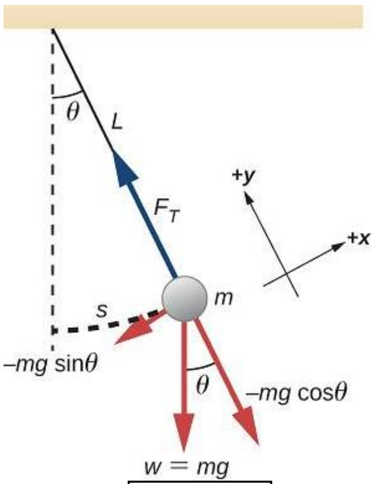


Figure 1

This leaves a *net* restoring force back toward the equilibrium position at $\theta = 0$.

When a simple pendulum is displaced from its equilibrium position, there will be a restoring force that moves the pendulum back towards its equilibrium position. The restoring force is opposite and directly proportional to the displacement $\boldsymbol{x}$ from the equilibrium position, so that it satisfies the relationship:

$$\boldsymbol{F} = -\boldsymbol{kx} \quad \ldots\ldots.. (1)$$

If a pendulum is set in motion so that is swings back and forth, its motion will be periodic. The time that it takes to make one complete oscillation is defined as the **period** (T). and the motion of the pendulum will be simple harmonic motion and its period can be calculated using the equation for the period of *SHM*:

$$T = 2\pi\sqrt{\frac{m}{k}} \quad \ldots\ldots.. (2)$$

We should note that for small angles (<15º), $\sin\theta \approx \theta$ ($sin\theta$ and θ differ by about 1% or less at smaller angles). Thus, the restoring force $\boldsymbol{F}$ is**:**

$$\boldsymbol{F} \approx -\boldsymbol{mg\theta} \quad \ldots\ldots. (3)$$

The displacement $\boldsymbol{s}$ is directly proportional to $\boldsymbol{\theta}$. When $\boldsymbol{\theta}$ is expressed in radians, the arc length in a circle is related to its radius (L in this instance) by $\theta = s/L$**.** Then for small angles the expression for the restoring force is:

$$\boldsymbol{F} \approx -\boldsymbol{mg}\frac{\boldsymbol{s}}{\boldsymbol{L}} \quad \ldots\ldots. (4)$$

By comparison equation (1) with equation (4), we get: $\boldsymbol{k} = \boldsymbol{mg/L}$. {The displacement is given by $\boldsymbol{x} = \boldsymbol{s}$}.

Substituting $\boldsymbol{k}$ value in equation (2), we can find *the period of a pendulum* for amplitudes less than about 15º:

$$T = 2\pi\sqrt{\frac{L}{g}} \ldots\ldots\ldots (5)$$

This result is shows: the *only* things that affect the period of a simple pendulum are its length and the acceleration due to gravity. By squaring both sides of the equation yields:

$$T^2 = 4\pi^2 \frac{L}{g} \quad \ldots\ldots\ldots\ldots (6)$$

which give us the acceleration due to gravity ($\boldsymbol{g}$).

Equipment: A clamp with stand, A thread, A bob, Vernier caliper, Stop/watch, Meter scale.

Procedure:

1. Set the pendulum apparatus as shown in Figure 2.

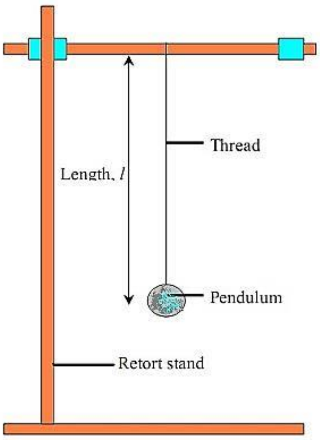


Figure 2

2. Measure the length (L) of the thread from the point of suspension to the middle of the bob .

3. Move bob using the hand at an angle **not** more than 10^0 and leave it.

4. Count 20 complete oscillations, and read the required time when the 20th oscillation is complete (T_{20}) using a stop/watch.

   "The stop/watch is started when the pendulum crosses the equilibrium position to any one side. When it passes the equilibrium position in the same direction the next time it has completed one oscillation".

5. Repeat the experiment for different lengths, and take observation of the time for 20 oscillation for each new length.

6. Tabulated the reading as the table:

L (cm)	L (m)	T_{20} (sec)	$T = T_{20}/20$ (sec)	T^2 (sec^2)

7. Plot a graph of T^2 on the *x-axis* against L on the *y-axis*.
8. Make the "best fit line" to obtain the slope of this line.
9. The magnitude of slope must multiplied by $4\pi^2$ to calculate the gravity acceleration according to Equation (6).

Question of the experiment:

Q1/ Define the following:

- Restoring force
- Simple Pendulum

Q2/ What is the length of a pendulum with a period of 10 seconds?

Q3/ What is the effect on the period of a pendulum if you double its length?

Q4/ What is the effect on the period of a pendulum if you decrease its length by 5%?

Q5/ Compare the theoretical result (9.8 m/sec^2) with the measured experimental result (your result) and calculate the percent difference.

$$\%\ \text{Difference} = \frac{\text{Experimental Result} - \text{Theoretical Result}}{\text{Theoretical Result}} \times 100\%.$$

Physics

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First Stage

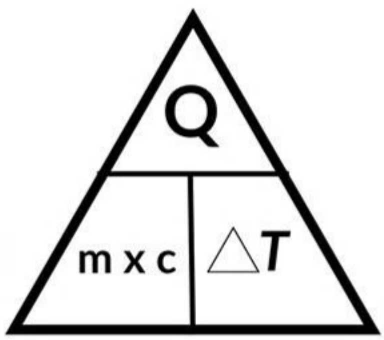
ALNOOR UNIVERSITY COLLEGE

Lecture 7

Specific Heat in Thermodynamics

- The **specific heat** of a material is the amount of energy that must be added to the material to raise the temperature of a unit mass by one temperature unit.
- **Or** the quantity of heat required to raise the temperature of one gram of a substance by one Celsius degree.
- The heat gained or lost by an object depends on:
  - the mass,
  - the change in temperature,
  - the specific heat of the substance.

$$Q = mC\,\Delta T = mC\,(T_f - T_i)$$



- The units of specific heat are usually:

  J/kg.°C or J/kg. °K

- **Equal** masses of **different** substances needed **different** amounts of heat to raise them through the same temperature interval.

Specific Heat of Common Substances			
Material	Specific Heat (J/kg·K)	Material	Specific Heat (J/kg·K)
Aluminum	897	Lead	130
Brass	376	Methanol	2450
Carbon	710	Silver	235
Copper	385	Steam	2020
Glass	840	Water	4180
Ice	2060	Zinc	388
Iron	450		

- The specific heat of water is = 1 calorie/gram. °C
= 4.186 joule/gram.°C which is **higher** than any other common substance.
- As a result, water plays a very important role in temperature regulation.

Example:

Q1- When the temperature of 10 kg of water is increased by 5K, the heat absorbed is:

$$Q = (10kg)(4180\ J/kg.K)(5K)$$
$$= 2.1\times 10^5\ J.$$

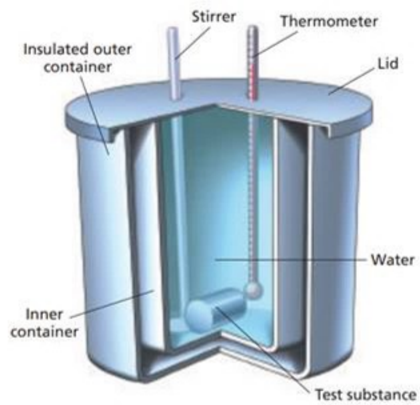
Q2- A 5.1kg cast-iron skillet is heated on the stove from 295K to 450 K. How much heat had to be transferred to the iron?

$$Q = (5.1kg)(450\ J/kg.K)(450\text{-}295K)$$
$$= 3.6\times 10^5\ J.$$

H.W.: A hot 1 kg chunk of copper is allowed to cool to 100°C. If the copper gave off 231 kJ of energy, what was the initial temperature of the copper?

Calorimetry: Measuring Specific Heat

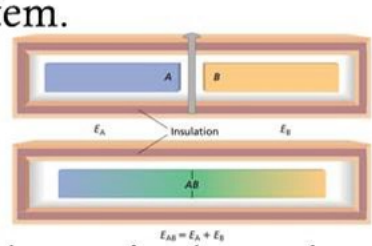
- A **simple calorimeter** is a device used to measure changes in thermal energy.
- A measured mass of a substance that has been heated to a high temperature is placed in the calorimeter.



- The calorimeter also contains a *known* mass of cold water at a measured temperature.
- The heat released by the substance is transferred to the cooler water.
- The change in thermal energy of the substance is calculated using the resulting increase in the water temperature.

- The operation of a calorimeter depends on the conservation of energy in an isolated, closed system.

$$E_A + E_B = \textbf{constant}$$



- In an isolated, closed system, the change in thermal energy is equal to the heat transferred *because no work is done*.

$$\Delta E = Q = mC\,\Delta T = mC\,(T_f - T_i)$$

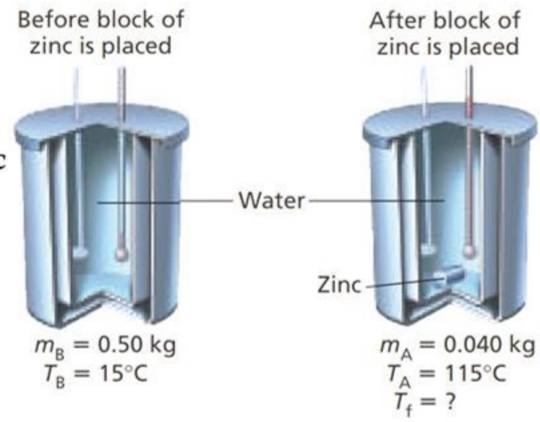
$$m_A C_A \Delta T_A + m_B C_B \Delta T_B = 0$$

If $\Delta T = T_f - T_i$ ….. then:

$$T_f = \frac{m_A C_A T_A - m_B C_B T_B}{m_A C_A + m_B C_B}$$

Example:

- A calorimeter contains 0.5kg of water at 15°C. A 0.04kg block of zinc at 115°C is placed in the water. What is the final temperature of the system?



- Let zinc be sample A and water be sample B.
- Sketch the transfer of heat from the hotter zinc to the cooler water

$$T_f = \frac{m_A C_A T_A - m_B C_B T_B}{m_A C_A + m_B C_B}$$

$$= \frac{(0.04\text{kg})(388\ \text{J/kg.°C})(115°\text{C}) - (0.5\text{kg})(4180\ \text{J/kg.°C})(15°\text{C})}{(0.04\text{kg})(388\ \text{J/kg.°C}) + (0.5\text{kg})(4180\ \text{J/kg.°C})}$$

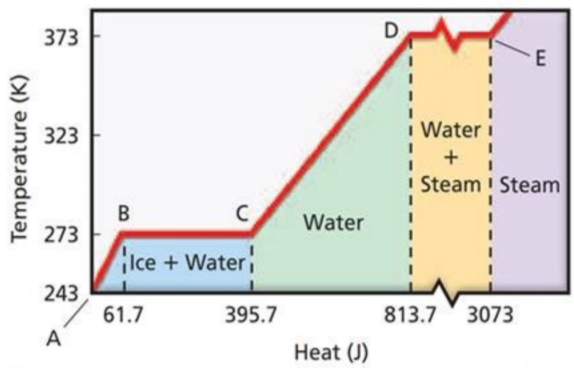
$$= 16°\text{C}$$

Changes of State

- The three most common states of matter are solids, liquids, and gases.
- As the temperature of a solid is raised, it usually changes to a liquid. At even higher temperatures, it becomes a gas.
- How can these changes be explained?

"When the thermal energy of the solid is increased, the motion of the particles also increases, as does the temperature.

- The changes of state as thermal energy is added to 1g of water starting at ice and continuing until it reaches steam.



- The heat, **Q**, required to **melt** a solid of mass (m) is given by:

$$Q = mH_f$$

- When a liquid **freezes**, an amount of heat:

$$Q = -\,mH_f\,,$$

must be removed from the liquid to turn it into a solid.

- *Similarly*, the heat, Q, required to **vaporize** a mass, (m) of liquid is given by:

$$Q = mH_v$$

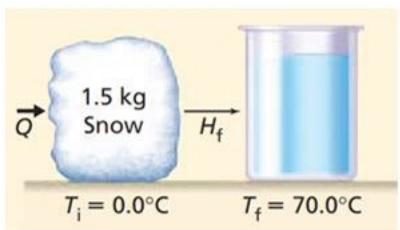
- When a vapor **condenses** to a liquid, an amount of heat,

$$Q = -\,mH_v$$

must be removed from the vapor.

Example:

1. Suppose that you are camping in the mountains. You need to melt 1.5 kg of snow at 0°C and heat it to 70°C to make hot cocoa. How much heat will be needed?



- Calculate the heat needed to melt ice.

$$Q_{melt\ of\ ice} = mH_f$$
$$= (1.5\text{ kg})(3.34\times10^5\text{J/kg})$$
$$= 5.01\times10^5\text{J} = 5.01\times10^2 KJ$$

- Calculate the temperature change:

$$\Delta T = (T_f - T_i)$$
$$= 70°C - 0°C$$
$$= 70°C$$

- Calculate the heat needed to raise the water temperature.

$$Q_{heat\ liquid} = mC\Delta T$$
$$= (1.50\ kg)(4180\ J/kg°C)(70°C)$$
$$= 4.39\times10^5 J$$
$$= 4.39\times10^2 KJ$$

- Calculate the total amount of heat needed.

$$Q_{total} = Q_{melt\ of\ ice} + Q_{heat\ liquid}$$
$$= 5.01\times10^2 KJ + 4.39\times10^2 KJ$$
$$= 9.4\times10^2 KJ$$
$$= 9.4\times10^5 J$$

2. A 2×10^{-2}g sample of water at 60°C is heated to steam at 140°C. How much heat is absorbed?

$$Q_{total} = mC_{water}\Delta T + mH_v + mC_{steam}\Delta T$$
$$= (0.2\ kg)(4180\ J/kg°C)(100°C-60°C)$$
$$+ (0.2\ kg)(2.26\times10^6 J/kg)$$
$$+ (0.2\ kg)(2020\ J/kg°C)(140°C-100°C)$$
$$= 502\ kJ$$

H.W.: How much heat is absorbed by 1×10^2g of ice at -20°C to become water at 0°C?

Torque and Rotational Equilibrium

Purpose: To investigate torques on rigid bodies and find unknown metal mass.

Theory: The force that produces or tends to produce rotation or torsion called as **Torque** or *moment of a force*, it is the measure of the force that can cause an object to rotate about an axis. In physics, it is simply the tendency of a force to turn or twist.

About axis of rotation (Figure 1) torque is the vector product of the force and the distance to the axis (lever arm):

$$\vec{\tau} = \vec{F} \times \vec{r} \quad \text{……….. (1)}$$

where $\vec{F}$: is the strength of the force that is acting on the arm from direction that is perpendicular to the arm.

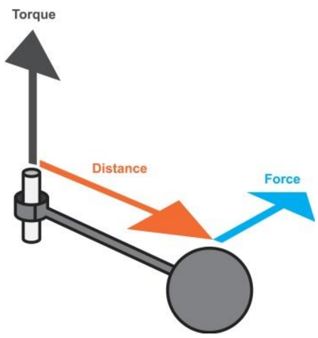


Figure 1

$\vec{r}$: is the lever arm.

Therefore, the magnitude of the torque is:

$$\tau = F\, r\, \sin\theta$$

Torque is a vector quantity. Its direction is normal to the plane containing **r** and **F**. When you cross **r** into **F** using the right-hand rule, your thumb points in the direction of the torque.

For convenience, torques are designated by the circular directions of motion that they tend to cause (clockwise and counter-clockwise).

A rigid body can rotate about a specific axis in only two directions, clockwise or counter-clockwise (Figure 2). *Clockwise torques* produce clockwise rotational motion and *counterclockwise torques* cause counterclockwise rotational motion.

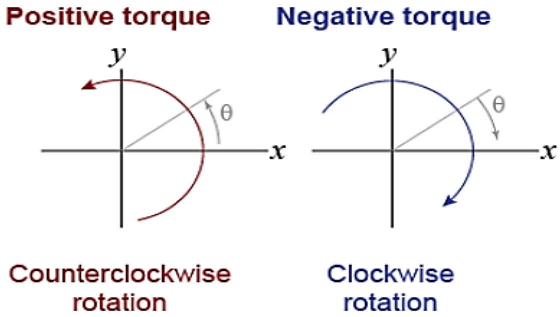


Figure 2

The rotation will not begin or change if the applied torques are balance (the system in rotational equilibrium). The condition for rotational equilibrium is that "the net torque on an object about some point in the body is zero":

$$\sum \vec{\tau} = \sum \vec{\tau}_{CCW} + \sum \vec{\tau}_{CW} = 0 \ \ldots\ldots\ldots. (2)$$

where $\vec{\tau}_{CCW}$ and $\vec{\tau}_{CW}$ are the counterclockwise and clockwise torques. Conventionally, the counterclockwise direction is positive (Positive torque), and the clockwise direction is negative (Negative torque).

For the system in Figure 3, the condition for rotational equilibrium becomes:

$$F_1 r_1 = F_2 r_2 + F_3 r_3 \ \ldots\ldots\ldots. (3)$$

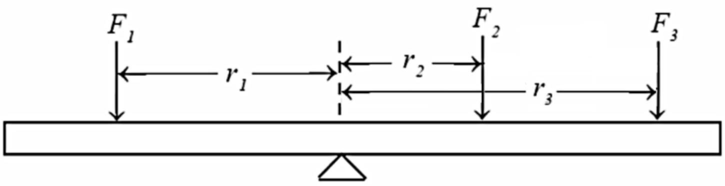


Figure 3

In this case the counterclockwise torque is $F_1 r_1$ and the clockwise torques are $F_2 r_2$ and $F_3 r_3$. According to Newton's Second Law ($W_i = F_i = mg$):

$$m_1 r_1 = m_2 r_2 + m_3 r_3 \quad \ldots\ldots\ldots\ldots (4)$$

You can use the equation of balanced torques to find an **unknown quantity**. Assume the bar above is in static equilibrium and the force exerted on the bar are due to three masses hanging at the indicated positions. Then the unknown mass (for example m_1) is:

$$m_1 = \frac{m_2 r_2 + m_3 r_3}{r_1} \quad \ldots\ldots\ldots\ldots (5)$$

Equipment: Lab balance, Meter stick, Balance stand for meter stick, Set of mass, Hooked mass set, small & unknown metal mass.

Procedure:

1. Balance the meter stick in a horizontal position on its supports with no weights attached.
2. Suspend three masses from the meter stick as indicated in the sketch (Figure 4) and move them until you balance the meter stick. Record the mass values and their positions.

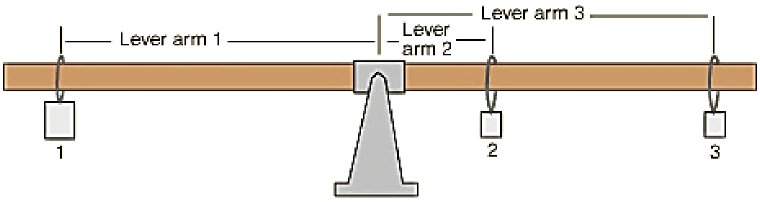


Figure 4

3. Determine the lever arm associated with each mass and record the values in the data table below. Compute the mass times the lever arm for each mass (The torque is the weight times the lever arm).

	Mass (g)	Lever arm (cm)	Direction (CW or CCW)	Torque (g.cm)
1.				
2.				
3.				

4. Compare the clockwise and counterclockwise torques (by Equation 4) to find how much the net torque differ from the theoretical value of zero.
5. To find an **unknown metal mass**: restore balance, then suspend unknown mass from one side of the meter stick.
6. Adjusting the position to balance the system, then use the equilibrium condition to determine the mass (Equation 5).
7. Finally, check your result by measuring the unknown mass with for example electronic balance (here: two weighs must be equal), **or** by suspending a block that has the same mass value as you found (here: the system must be balance).

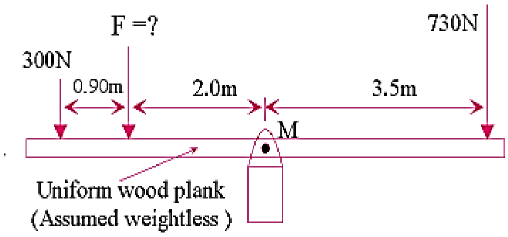
Question of the experiment:

Q1/ Define:

- Torque,
- Rotational equilibrium

Q2/ A seesaw support two people who weigh 455N and 535N, respectively. The 535N person is 1.5 m from the center. Where does the smaller person sit to balance the seesaw?

Q3/ Find the unknown force F that brings the seesaw in rotational equilibrium.



Dr. Huda Masood AL-Zacko

Viscosity of Liquid

Purpose: Determination the coefficient of viscosity for glycerin using a small ball drop device.

Theory: When a body falls through a highly viscous liquid, it is retarded by the force of *viscosity* exerted on it by the fluid. This force is *frictional force* between different layers of the liquid and the body.

When we gently place a ball on the surface of the liquid, as the ball is immersed into the liquid, three different forces act on the ball. These are:

- **i.** Weight of the ball, F_w which acts vertically downward.
- **ii.** Buoyancy force of the liquid on the ball, F_b which acts vertically upward.
- **iii.** Drag force on the ball due to *viscosity* of the liquid, F_d which always acts vertically upward.

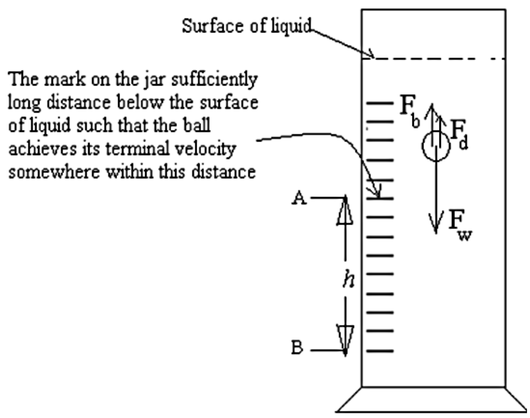


Figure 1

Let the radius of the ball r, then the volume of the ball is $V = \frac{4}{3}\pi r^3$ and the mass of the ball is $m = \sigma V$, where σ is the density of the ball's material. So, the weight of the ball is:

$$F_w = mg = \sigma V g = \sigma \left(\frac{4}{3}\pi r^3\right) g \quad ..... 1$$

When a ball is dropped into a fluid sample the gravitational force (F_w) on the ball is *larger* than the **buoyancy** force $\boldsymbol{F_b}$. This force can get using Archimedes principle for buoyancy of liquid on the ball (where ρ is the density of liquid):

$$F_b = \rho \left(\frac{4}{3}\pi r^3\right) g \quad \ldots\ldots\ 2$$

So the net driving force F on the ball is:

$$F = F_w - F_b = (\sigma - \rho)\left(\frac{4}{3}\pi r^3\right) g \quad \ldots\ldots\ 3$$

After a period time, the ball stops accelerating and falls with a constant speed called the **terminal speed**, and the net driving force will equilibrium with drag force (the net force is zero) that given due to viscosity by **Stock's law:**

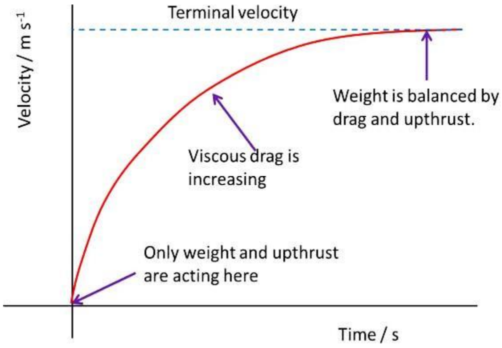


Figure 2

$$F_d = 6\,\pi\, r\, \eta\, v \quad \ldots\ldots\ 4$$

where v is the velocity of the ball and η is the coefficient of viscosity of the liquid, then:

$$F = F_d \quad \ldots\ldots\ 5$$

or

$$F_w = F_b + F_d \quad \ldots\ldots 6$$

Using (1), (2), (3) and (6) we can show that:

$$\eta = \frac{2}{9}\frac{r^2}{v}(\sigma - \rho) g \quad \ldots\ldots\ 7$$

Equipment: Tiny stainless steel balls, Glass cylinder, Stop watch, Glycerin, and Two rubber bands.

Procedure:

1. Write the density of glycerin $\rho = 1.23\ g/cm^3$, and density of the ball's material, $\sigma = 7.8\ g/cm^3$.
2. Select the same sized balls that dropped into a measuring cylinder containing glycerin. Then measure ball's diameter using a Vernier calipers.
3. Fix a mark, A (as shown in figure 1) on a cylinder below the surface of glycerin such that the ball achieves its terminal velocity while passing this mark. Fix another mark near the bottom of the cylinder (mark B in Figure 1).

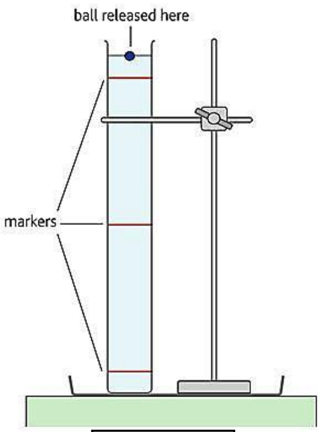


Figure 3

4. Measure the distance (h) between the two rubber bands (marks) and write it in the table.
5. Drop the ball at the middle of the top surface of the liquid. Then recorded the time (t) taken to travel a ball between two marks on the cylinder (as shown in Figure 3) by a stop watch. Take t_1 and t_2,

then measure the average readings $\bar{t}$ to reduce or eliminate any error present.

6. Repeat above steps with different values of dropping distance (h). Then tabulate all the data as given below.

h (cm)	t_1(sec)	t_2 (sec)	$\bar{t}$ (sec)

7. Plot graph with the distance (h) on the *y-axis* and the average time ($\bar{t}$) on the *x-axis*. The gradient of line of best fit will be the velocity of ball (in cm per sec).
8. Finally use equation (7) to measure the coefficient of glycerin's viscosity, by: $\eta = \frac{2}{9}\frac{r^2(\sigma-\rho)g}{slope}$

Question of the experiment:

Q1/ Define:

- Stock's law,
- Buoyancy force,
- Terminal velocity.

Q2/ A ball of diameter 2.5mm is made of steel. It is released into glycerin. Calculate:

(a) Weight of the ball, (b) Buoyancy force, and the terminal velocity of ball. (use the coefficient of glycerin's viscosity from your result).