UNIT 4 - MATTER:

Matter:
Matter is anything that has mass and takes up space. Anything around us and in the entire universe can be classified as either matter or energy.

The Particle Theory of Matter:
1. Matter is made up of tiny particles called atoms & molecules.
2. Particles of matter in solids, liquids and gases are in constant motion.
3. Particles of matter are held together by very strong electric forces.
4. There are empty spaces between the particles of matter that are very large compared to the particles themselves.
5. Each substance has unique particles that are different from the particles of other substances.
6. Temperature affects the speed of the particles, the higher the temperature, the faster the speed of the particles.
7. More.....

The following scientific phenomena can be explained by particle theory:
1. Pure substance are homogeneous (one phase - one unique kind of particle)
2. Physical changes - melting, evaporation, sublimation, dissolving....
3. Characteristic physical properties - density, viscosity, electrical & thermal conductivity

Intermolecular forces and potential energy:
1. Particles of matter in solids, liquids and gases are in constant motion at all temperatures above absolute zero that is zero kelvin.
2. The temperature and thermal energy of particles are associated with the kinetic energy of particles.
3. The particles or molecules that exert electrostatic force on each other give them electrical potential energy.
4. The forces between two particles depend upon the distribution of electrons in the molecules and separation of molecules.
5. At a very small distance between the molecules the net force between them must be repulsive otherwise the mass would collapse into each other.
6. At very large distance the attractive force must be negligible otherwise the gases would change into liquids or solids without any compression or condensation.

Consider two isolated molecules whose separation is such that they are exerting attractive forces on each other. If one of the molecules were to be removed to infinity, work would have to be done on it in order to overcome the attractive force, and therefore its potential energy would increase. However, it is convenient to regard the potential energy of each
molecule as being zero when their separation is infinite, because at such a separation they have no influence on each other and therefore when two molecules are attracting each other their potential energy is negative.  

\[ \Delta W = F \Delta r \]

Where \( \Delta W \) is the work done, \( F \) is the force attraction and \( \Delta r \) is the small distance it moved. Then the resulting change in the potential energy is

\[ \Delta E = -\Delta W \]

\[ \Delta E = -F \Delta r \]

\[ F = -\Delta E/\Delta r \]

Or in limit form

\[ F = -\tfrac{dE}{dr} \]

**Solid:**

Particles of solids are held in place by strong electrostatic forces and are densely packed together. Particles of solids vibrate constantly due to their internal energy but they cannot move from one place to another. Particles of solids possess only **vibrational energy**.

**liquids:**

Particles of liquids are kept together by forces of attraction that are weaker than those of solid particles. Within the walls of the container they can move from place to place bumping into the sides of the container and into other particles. This type of energy is called **translational energy**. This energy gives a liquid the ability to flow and be poured and to spread when a liquid is spilled. Liquid particles also have **vibrational energy**.

**Gases:**

In gases the forces of attraction that hold the particle together are very weak and that the spaces between them are much larger than the spaces between solid and liquid particles. Particles of gases can move from place to place within a container bumping against the walls of the container and against other particles. They rotate and vibrate at the same time. Particles of gases have **rotational, translational and vibrational energy**. This explains why they can escape from a container very easily and they can put pressure on the side of the container (example a balloon or a tire).

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1. [www.chem.neu.edu/.../Lectures/Lecture04.htm](http://www.chem.neu.edu/.../Lectures/Lecture04.htm)
Comparison of Solids liquids and gases:

<table>
<thead>
<tr>
<th>Solids</th>
<th>Liquids</th>
<th>Gases</th>
</tr>
</thead>
<tbody>
<tr>
<td>retains a fixed volume and shape rigid - particles locked into place</td>
<td>assumes the shape of the part of the container which it occupies particles can move/slide past one another</td>
<td>assumes the shape and volume of its container particles can move past one another</td>
</tr>
<tr>
<td>not easily compressible little free space between particles</td>
<td>not easily compressible little free space between particles</td>
<td>compressible lots of free space between particles</td>
</tr>
<tr>
<td>not flow easily rigid - particles cannot move/slide past one another</td>
<td>flows easily particles can move/slide past one another</td>
<td>flows easily particles can move past one another</td>
</tr>
</tbody>
</table>

Brownian motion:

Random movement of particle of liquids or gases is called Brownian motion. It was discovered by Scottish Botanist Robert Brown in 1827. When he looked at the suspended pollen grains in the water through a microscope, he noticed that the pollen grains were in state of continuous motion. The motion was both random and jerky. Brownian motion can be observed when small particles of any kind are suspended in fluid for example smoke particles suspended in air. This motion can be describe as it:

1. Increases with the increase of motion of the fluid
2. Deceasing the size of suspended particles

Brownian motion is now regarded as the strong evidence that fluids are composed of molecules in a state of continuous random motion.

Pressure:

Pressure is defined as the force applied by an object due to say its weight to the area in contact.

\[
\text{Pressure} = \frac{\text{force applied at right angle to surface}}{\text{area of contact}}
\]

\[
P = \frac{F}{A}
\]

The unit of pressure is N/m² or pascal (with small p) or Pa. Although the force applied is vector quantity the pressure is scalar quantity i.e. the pressure has no direction.

Pressure due to fluid of uniform density is defined as
Pressure = density of the fluid \times \text{the gravity} \times \text{height of depth of the fluid}

\[ P = \rho \times g \times h \]

**Melting, boiling and evaporation:**

There are two types of energies associated with the matter and intermolecular bonding, the kinetic energy and electrical potential energy. The kinetic energy is described as the motion of molecules at their mean position which increases with the increase of temperature. The electrical potential energy is due the presence of charges that create molecular bonding. When the temperature increases the heat energy increases the kinetic energy of the molecules and they vibrate at the higher rate. At boiling point the maximum possible kinetic energy, at that particular atmospheric pressure, is achieved. The further increase of heat energy is used to increase the potential energy of molecules and to break the intermolecular bonding, that is the work is been done to break the intermolecular bond and evaporation occur.

At A, T or KE increases and PE is constant.

At B, the ice starts to melt at 0°C. T or KE is constant and PE increases until all the ice is melted.

At C, T or KE increases and PE is constant.

At D, the water starts to boil at 100°C. KE is constant and PE increases until all the water evaporated.

At E, T or KE increases and PE is constant.
At E, T or KE decreases and PE is constant.

At D, the water vapor starts to condense. T or KE is constant and PE decreases until all the gas is condensed.

At C, T or KE decreases and PE is constant.

At B, the water starts to freeze at 0°C. T or KE is constant and PE decreases until all the water is frozen.

At A, T or KE decreases and PE is constant.

TYPES OF SOLIDS:

**Crystalline solids:**

1. In crystalline solids the atoms (or ions or molecules) are arranged in a regular three dimensional array. There is basic unit called *unit cell* which is repeated throughout the structure in all three dimensions.

2. The way the atoms are arranged shows the physical property of the solid. For example
   a. Graphite and diamond are both crystalline form of carbon but graphite is soft and used in pencil where as the diamond is one of the hardest material known.
   b. Diamond is more dense than graphite.
   c. Diamond is transparent and graphite is opaque.
   d. Diamond is insulator and graphite is conductor.

3. Crystalline solids have definite melting point.

4. When atoms are arranged in a regular pattern their total potential energy is less than it would be if they are packed irregularly.

**Non-crystalline solids:**

**Amorphous solids:**

1. It has no regular outlines, no directional properties no long range regular arrangement of atoms.

2. Amorphous solids have no definite melting point.

3. Example of amorphous solids are glass, wax

4. Window glass is the common example of non-crystalline solids. There melting temperature ranges from 400 °C to 700 °C depend up how they made and what they are used for.

5. At room temperature glass is hard brittle.

6. Most glasses absorb ultraviolet rays but pass the infra-red rays.

7. All glasses are inorganic in nature and produced by the mixture of SiO₂, CaO, Na₂O.

8. They are electrical insulator.
Polymers:
1. Polymers have large molecules in the form of long chains. Each chain consists of a large number of small molecules, known as monomers. They are joined by strong covalent bonds. They are usually organic.
2. The chain may be either linear, branched or cross-linked.
3. They may be either organic for example rubber, wool, cellulose and proteins or synthetic for example polythene (plastic) or nylon.

Metals:
1. The periodic table separates the elements into three groups: the metals (green in the table), nonmetals (orange), and metalloids (blue).
2. Most elements are metals. They are typically shiny, good conductors of heat and electricity, have a high density, and only melt at high temperatures. Metals are ductile and malleable, so their shape can be easily changed into thin wires or sheets. Metals will corrode, gradually wearing away like rusting iron.
3. Nonmetals, on the right side of the periodic table, are very different from metals. Their surface is dull and they are poor conductor of heat and electricity. As compared to metals, they have low density and will melt at low temperatures. The shape of a nonmetal cannot be changed easily as they tend to be brittle and will break.
4. Elements that have properties of both metals and nonmetals are called metalloids. They can be shiny or dull and their shape is easily changed. Metalloids typically conduct heat and electricity better than nonmetals but not as well as metals.

http://www.windows.ucar.edu/tour/link=/earth/geology/metals.html&edu=high
FORCE AND EXTENSION:
Objects like spring stretches or compresses when a force is applied. When the spring stretches or compresses, it undergoes a displacement of $\Delta x (=x_f - x_i)$ from its original position or unstrained length. In other words the deformation of spring happens. Deformation can be because of compression (compressive) or because of expansion (tensile) of the spring. The relationship between force applied (i.e. load) and extension $\Delta x$ can be expressed as:

$$F_{app} \propto \Delta x$$

or

$$F_{app} = k\Delta x$$

Where $k$ is the spring constant, which sometimes referred to as the stiffness of the spring. The above statement is called Hooke’s law.

In accordance with the Newton’s third law of motion the spring exerts an equal and opposite force on the block. This force is called restoring force $F_s$ and equation can be written as:

$$F_s = -k\Delta x$$

Hooke’s Law:
“For an elastic material the extension of a spring or a wire is directly proportional to the force applied on it, provided the elastic limit is not reached.”

Elastic material:
A material is said to be elastic if it returns to its original size and shape when the load which has been deforming it is removed. If not then it is called plastic.

Elastic limit:
This is the maximum load which a body can experience and still regain its original size shape once the load has been removed. The elastic limit sometimes coincides with the limit of proportionality.

$$F_{app} = k\Delta x$$

Elastic constant or spring constant:
The spring constant ‘$k$’ is a measure of how stiff the spring is. A spring that is very hard to stretch out has a large spring constant. A spring that is easy to stretch has a small spring constant. As the term spring constant implies, the spring constant is always the same for a given spring. It is the force applied per unit extension. The unit of spring constant is N m$^{-1}$. 
Spring constant in series and in parallel:

In above combinations of spring

Example X → spring constant is $2k$ and extension would be $\frac{1}{2}x$

Example Y → spring constant is $k$ and extension would be $x$.

Example Z → spring constant is $\frac{2}{3}k$ and extension would be $\frac{3}{2}x$.

**Strain:**

Strain is defined as the ratio of extension $\Delta x$ and original length $x$ of a spring or string when the force is applied.

$$ strain = \frac{extension}{original \ length} $$

$$ \varepsilon = \frac{\Delta x}{x} $$

**Stress:**

Stress produce within an object when there is a stress. Stress is defined as the force applied at a unit area normal to the force. It could be tensile or compressive. The unit of stress is force per unit area squared (N m$^2$). This is also the unit of pressure so the stress can be sometimes expressed in pascal (Pa).

$$ stress = \frac{force}{area \ normal \ to \ the \ force} $$

$$ \sigma = \frac{F}{A} $$
Young modulus:

It is the ratio of stress over strain. Mathematically, the Young modulus $E$ can be expressed as

$$E = \frac{\sigma}{\varepsilon} = \frac{F/A}{\Delta x/x}$$

The unit of Young modulus is pascal (Pa).

In the above diagram, we see that, if our metal rod is tested by increasing the tension in the rod, the deformation increases. In the first region, the deformation increases in proportion to the force. That is, if the amount of force is doubled, the amount of deformation is doubled. This is a form of Hooke's Law and could be written this way: $F = k\Delta x$ where $k$ is a constant depending on the material (and is sometimes called the spring constant). After enough force has been applied, the material enters the plastic region - where the force and the deformation are not proportional, but rather a small amount of increase in force produces a large amount of deformation. In this region, the rod often begins to 'neck down', that is, the diameter becomes smaller as the rod is about to fail. Finally, the rod actually breaks.

The point at which the Elastic Region ends is called the elastic limit, or the proportional limit. In actuality, these two points are not quite the same. The Elastic Limit is the point at which permanent deformation occurs, that is, after the elastic limit, if the force is taken off the sample, it will not return to its original size and shape, permanent deformation has occurred. The Proportional Limit is the point at which the deformation is no longer directly proportional to the applied force (Hooke's Law no longer holds). Although these two points are slightly different, we will treat them as the same in this course.
Similarly the graph between stress and strain has the same shape and regions as the force versus extension in the previous graph. In the elastic (linear) region, since stress is directly proportional to strain, the ratio of stress/strain will be a constant (and actually equal to the slope of the linear portion of the graph). This constant is known as Young's Modulus, $E$ which is another form of Hooke's Law.

<table>
<thead>
<tr>
<th>Material</th>
<th>Young modulus ($E$) in Pa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>$0.71 \times 10^{11}$</td>
</tr>
<tr>
<td>Copper</td>
<td>$1.1 \times 10^{11}$</td>
</tr>
<tr>
<td>Steel</td>
<td>$2.1 \times 10^{11}$</td>
</tr>
<tr>
<td>glass</td>
<td>$0.41 \times 10^{11}$</td>
</tr>
</tbody>
</table>

**Elastic Hysteresis:**

The above figure shows the force-extension graph of a sample of rubber for loading and unloading. The extension due to any given force is greater during the unloading than during loading. The effect is called **elastic hysteresis** and the region enclosed by the two curves is called **hysteresis loop**. Rubber has a property that when it is stretched it becomes warmer. When the force is released its temperature falls but it remains a little bit warmer than it was initially. The net increase in the heat content of the sample during the cycle is equal to the area of the hysteresis loop.

1. Rubber can stretched 10 times its original length compare to copper that extends only $1/10000^{th}$ of its original size before it reaches its elastic limit.
2. Rubber does not obey Hooke’s law.
3. The rubbers that have large hysteresis loops are useful as vibration absorber for any vibrating machinery.
4. Rubber used in making tyres has small hysteresis loop, so that as little heat as possible is generated in a tyre.

**Experiment to determine the Young modulus of copper wire:**

Young module of a metal in the form of a wire for example copper may be measured by applying loads and measuring extension due to these loads. As shown above the Young modulus is expressed by
The area of cross section $A$ and original length $x$ can be calculated by measuring diameter using micrometer screw gauge and meter rule.

The diagram shows the suitable arrangement for performing the experiment. The copper wire of uniform thickness attached to a clamp pass through a pulley and masses are hanged at the other end. The paper sticker is attached as pointer on the wire along with meter rule. When the masses are increased the wire expands and the expansion is measured by the displacement $\Delta x$ of pointer from the initial position.

The load $F$ is calculated by $F=mxg$. The different values of $F$ (on x axis) and $\Delta x$ (on y-axis) are tabulated and the graph is plotted. The gradient of the graph is equal to $\frac{L}{EA}$ so the Young modulus $E$ is equal to $\frac{L}{(A\times\text{gradient})}$.

**Elastic and plastic materials:**

When the force or load is removed from an object and it returns to its original shape then the object is called **elastic material**. The amount of deformation, due to the force, from the original shape is called the **strain** of an object.

Plastic material is one which does not return to its original position that its shape and size do not change after removing the force or load which is deforming it. The plasticine is a good example. The perfectly plastic body is opposite to the elastic material.

Elasticity and plasticity is the physical property of any material and is different for different materials.

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3 http://media.photobucket.com/image/young%20modulus%20experiment/st2910/D2_Diagram2.jpg
**Strain energy:**
When the shape of an object is changed due to the forces applied on it then the object is a strained object. Since the shape of an object is changed the work must be done to cause this change. If the elastic limit is not reached then the work must be done by an object when returning back to its original shape after removing the applied force. This particular form of energy stored in an object due to work done is called strain potential energy or strain energy.

**Strain energy is the energy stored in an object due to the change of shape or size.**

Consider a wire whose extension is \( x \) when the force \( F \) is applied. It undergoes a very small extension \( dx \) when the amount of force \( F \) is considered constant then the work done between zero and \( x \) for \( dx \) is given by:

\[
W = \int_0^x F \, dx
\]

If the wire obeys the Hooke’s law then

\[
F = kx
\]

substitute the value of \( F \) in equation

\[
W = \int_0^x kx \, dx
\]

by solving the integration

\[
W = \frac{1}{2} kx^2
\]

or

\[
E_{\text{strain}} = W = \frac{1}{2} Fx
\]

This work done on the wire is called the strain energy or elastic potential energy stored in the wire.

If the wire has original length \( L \) and cross-sectional area \( A \) then the volume must be \( AL \)

\[
\text{Strain energy per unit volume} = \frac{1}{2} \frac{Fx}{AL}
\]

or

\[
\text{Strain energy per unit volume} = \frac{1}{2} \times \frac{F}{A} \times \frac{x}{L}
\]

or

\[
\text{Strain energy per unit volume} = \frac{1}{2} \times \text{stress} \times \text{strain}
\]

Please note that:

- The area under force-extension graph is strain energy stored in an object or work done in expanding or compressing the object.
- The area under the stress-strain graph is strain energy per unit volume stored in an object.
Ductile, brittle and polymeric material:

When an object is subjected to increasing stress it changes its shape, size or volume. Such a change in shape, size or volume is referred to as \textit{strain}. When stress is applied to an object, the object passes through 3 successive stages of deformation.

- \textit{Elastic Deformation} -- wherein the strain is reversible.
- \textit{Ductile Deformation} -- wherein the strain is irreversible.
- \textit{Fracture} -- irreversible strain wherein the material breaks

Material like copper is called ductile material, this means that it can be drawn in a wire without breaking. \textit{Ductile materials} have a small region of elastic behaviour and a large region of ductile behaviour before they fracture.

Material like glass that can be extended but do not show plastic deformation and will easily fracture are known as brittle materials. \textit{Brittle materials} have a small to large region of elastic behaviour, but only a small region of ductile behaviour before they fracture.

Polymeric materials are solids made of very large molecules, usually a compound of carbon. These molecules often take the form of long chains. If these chains certain amount of order, example if the chains are parallel, the material is referred to as crystalline polymer but if there is no order than it is called amorphous. Diamond is an example of crystalline polymer and glass is an example of amorphous polymer.
Summary of important points in stress-strain graphs:

a) OP is a straight line; in this region Hooke’s law is obeyed.
b) P is the limit of proportionality, up to this point the stress is proportional to the strain.
c) E is the elastic limit – up to E, if the load is removed the material will return to its original length although the stress may not be proportional to the strain up to this point.
d) Y is the yield point – between E and Y the material becomes plastic, that is, if the load is removed the material will contract but all the extension is not recoverable. The material follows the dotted line YS on the graph during contraction and the remaining extension is known as permanent deformation.
e) Z – after this point none of the extension is recoverable.
f) B – is the breaking stress point beyond which the material will break.

Comparison of different form of potential energies:

Potential energy is the energy stored in an object due to change its position or change of shape. The unit of potential energy is joules and mega joules. Most common potential energies are:

<table>
<thead>
<tr>
<th>Gravitational Potential Energy</th>
<th>Electrostatic potential energy</th>
<th>Elastic potential energy (strain energy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is due to earth gravitational force of attraction on objects around it.</td>
<td>It is due to the forces between two electric charges</td>
<td>It is the work needed to compress (or expand) a spring or energy stored in a spring when it compressed or expanded</td>
</tr>
<tr>
<td>It is always directed towards the centre of the earth. It is always attractive.</td>
<td>It is directed towards positive charge, that is from negative to positive. It may be attractive of repulsive</td>
<td>Its directed towards the mean of undisturbed position of the spring</td>
</tr>
<tr>
<td>Examples: an object of mass ‘m’ raised to the height ‘Δh’ above the surface.</td>
<td>Example: two electric charges $q_1$ and $q_2$ are separated by distance $r$.</td>
<td>Examples: stretched wire, twisted elastic band and compressed gases.</td>
</tr>
<tr>
<td>$\Delta E_{p,g} = m \times g \times Δh$</td>
<td>$E_{p,q} = \frac{1}{4\pi\varepsilon_0} \frac{q_1 \times q_2}{r}$</td>
<td>$E_{p,e} = \frac{1}{2} \times k \times x^2$</td>
</tr>
</tbody>
</table>