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PHYSICS HEAT

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HEAT AND THE EARTH

1

The surface of the earth, on average, receives:

- 17% of its heat directly from the Sun,
- 15% from solar radiation scattered by clouds,
- 68% from absorption of infrared radiation emitted by the atmosphere.

The greater part of the energy absorbed by the surface, 79%, is returned to the atmosphere in the form of radiation. The remainder, 21%, is transmitted to the atmosphere by conduction and as a by-product of the exchange of water. The surface can cool by evaporation and the associated heat is transmitted to the air as vapour, which recondenses to form clouds and either rain or snow.

The atmosphere can be thought of as a compressible fluid that is heated from below by the Earth and disturbed locally by energy absorbed from sunlight. Direct absorption of solar radiation is important mainly for the stratosphere and thermosphere. Transfer of energy by infrared radiation is a dominant method for heat transmission between the different atmospheric layers.

- The amount of heat from the sun that falls on a region determines the temperature range of the region.
- The temperature of the atmosphere, in turn, determines whether the moisture of the region will be in the form of water or ice.
- The amount and kinds of plant and animal life depends on the temperature of the environment.
- Bacteria that cause disease grow more rapidly at one temperature than at another; the temperature influences the problem of disease in some areas.

The amount of heat supplied to a location also affects human actions directly. It is a factor in determining where people will live, work, and build their communities. A dependable supply of heat energy is one of the very important factors in making our life and our world what they are.

Questions...

1. Write a short paragraph explaining how the Earth is heated by the Sun.
2. How does the Sun affect which parts of the Earth are warm or cold?
3. How does heat affect human behaviour? Give examples of how it affects:

   - work,
   - location of communities,
   - agriculture and industry.

ENERGY

2

In physics energy is the capacity for doing work. It may exist in;

- Potential,
- Kinetic,
- Thermal,
- Electrical,
- Chemical,
- Nuclear,
- Other various forms.

There is also energy in the process of transfer from one body to another. After it has been transferred, **energy is always designated according to its nature**. Heat transferred may become thermal energy, while work done may manifest itself in the form of mechanical energy.

All forms of energy are associated with motion. For example, any given body has kinetic energy if it is in motion. A tensioned device such as a spring, though at rest, has the potential for creating motion; it contains potential energy because of the way it is designed. Similarly, nuclear energy is potential energy because it results from the configuration of subatomic particles in the nucleus of an atom.

Energy can be converted from one form to another in various ways. Usable mechanical or electrical energy is, for instance, produced by many kinds of devices, including fuel-burning heat engines, generators, batteries, or fuel cells.

Questions...

1. What is a physics definition of energy?
2. Find out about and write a short description each on the types of energy listed above.
3. How can energy be converted from one type of energy to another? Give examples.

FUELS

3

The most important source of heat on Earth is the Sun.

The second most important source of heat is the store of natural fuels that are on and in the Earth. The most important of these fuels are:

- Coal,
- Oil,
- Gas,
- Wood.

These substances, however, do not provide heat constantly and automatically as the Sun does. They are composed of carbon, hydrogen, and other elements. When a fuel is raised to a certain temperature, it reacts chemically with oxygen. We call the reaction **burning**, or **combustion**. This reaction releases a large quantity of heat.

Electrical energy can be converted into heat also. This change of energy is made use of in many familiar appliances. The heat we get from electric heaters, toasters, and electric driers is produced by converting electrical energy to heat energy.

Many chemical reactions produce heat that is not due to oxidation. It is due to a conversion of chemical energy to heat as a reaction takes place. Some common reactions that are accompanied by heat are those that occur when acids or bases are mixed with water. For the future, the most important source of controllable heat may be the energy released when an atomic nucleus is split.

Questions...

1. How do the types of energy listed above differ from the energy given by the Sun?
2. Find out about and write short summaries of how the fuels listed above are manipulated, adapted and used.
3. How important is electrical energy in your life? Give examples.

TEMPERATURE

4

There is an important factor to remember when we talk about temperature. The temperature of a substance is nothing to do with the heat energy that can be gained from it but is:

- **a number on a scale which expresses its hotness.**

Temperature is important because it tells us how hot or cold something is and can be compared to the hotness or coldness of other substances.

Temperature is measured by a thermometer which can be of many types. The most common types are the ones we see which have a bulb containing either alcohol or mercury based liquids which expand up a tube. Temperature is measured in either in Fahrenheit or Celsius on these thermometers.

Daniel Gabriel Fahrenheit was a German physicist and maker of scientific instruments. He is best known for inventing the alcohol thermometer (1709) and mercury thermometer (1714) and for developing the Fahrenheit temperature scale; this scale is still commonly used in the United States. One of his notable discoveries was that water can remain liquid below its freezing point, and that the boiling point of liquids varies with atmospheric pressure.

The centigrade temperature scale is based on 0 for the freezing point of water and 100 for the boiling point of water and was invented in 1742 by the Swede **Anders Celsius**. It is sometimes called the centigrade scale because of the 100-degree interval between the defined points. The Celsius scale is in general use wherever metric units have become accepted, and it is used in scientific work everywhere.

It is often necessary to convert a temperature on one scale to a corresponding temperature on another. Some useful conversion relations are:

Fahrenheit to Celsius $^oC = 5/9\ (^oF - 32)$

Celsius to Fahrenheit $^oF = 9/5\ (^oC + 32)$

Questions...

1. Write a short history of how the measurement of heat developed.
2. What is the difference between Celsius and Fahrenheit and how can we convert them across the different scales?

HEAT - EFFECT ON SOLIDS

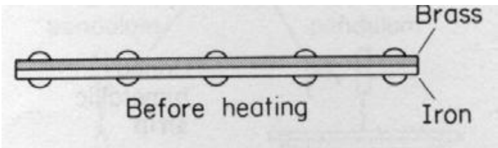
One thing is virtually guaranteed in the relationship between heat and solids; solids will always expand when subjected to heat. Of course it does depend on the type of solid and the amount of heat.

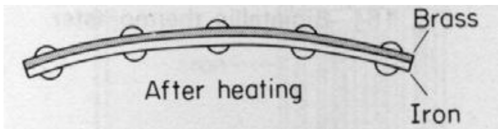
We can say that two main factors determine what effect heat has on solids:

- the type of solid,
- the amount of heat.

A simple illustration of this can be seen from looking at and comparing what happens to ice and Iron. Ice begins to melt from its solid state at the slightest rise in temperature from 0^0 Celsius. However, a piece of Iron will not melt until it is heated to very high temperatures. Even stone can be reduced to liquid form if the temperature is high enough, as can be seen by volcanic activity.

Another simple experiment to show how heat affects different solids is to rivet together two thin strips of different metals; brass and iron are a good example. When the riveted pieces are heated the brass expands more than the iron in the same temperature range. This forces the brass to bend.





There are many problems faced by this phenomenon of expansion of solids. Bridges are built with a few inches of 'breathing space' at each end to allow the concrete and metals to expand in hot weather. This avoids cracking. Railway lines used to be laid with spaces at each end for expansion. Today they are made to join, with expansion spaces further apart. One positive use of expansion in metals is in thermostats.

Questions...

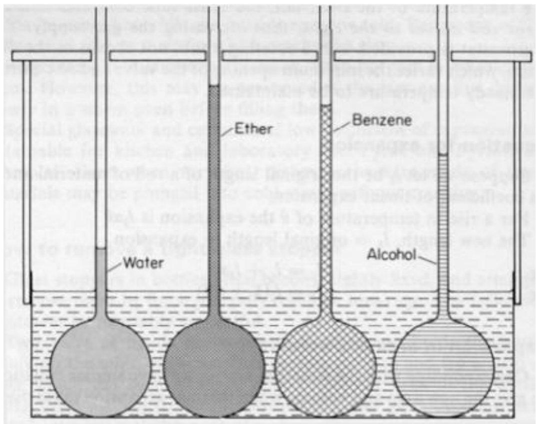
1. What factors determine how solids are affected by heat?
2. Make a list of solids which are affected by heat quite easily.
3. List the most heat resistant solids.

HEAT - EFFECT ON LIQUIDS

Heat affects liquids in different ways because liquids, like solids, react according to their chemical make-up. The main difference between liquids and solids is that liquids do not have a definite shape of their own and shape themselves according to the container they are put in. This means that measurement can be made in terms of volume changes. Another factor which always occurs in heating; an increase in volume always means a decrease in density because the amount of liquid is the same but it is filling a larger area.

Try an experiment. Using apparatus similar to that shown below, mark the thin tube sections at intervals. Prepare several containers in the same way, (the containers should be the same in order for comparisons to be made reliably). Heat different liquids at one preset temperature and see what happens. Use the following liquids:

- Water,
- Ether,
- Benzene,
- Alcohol.



Try the experiment at different temperatures.

When liquids are heated beyond their maximum tolerable temperature they then start to change into gases, (or vapours). The simplest illustration of this is the evaporation of water.

Questions...

1. What is the difference between measuring changes in solids and liquids which are affected by heat?
2. Make a list of liquids which are easily affected by heat.
3. Explain why some liquids are very sensitive to heat.

HEAT - EFFECT ON GASES

A gas has no definite shape and exhibits high fluidity. It tends to expand indefinitely and readily fills any container into which it is introduced. Gases are highly compressible, and under ordinary conditions they have a density approximately 1,000 times less than that of liquids. A small change in temperature or pressure generally produces a substantial change in the volume of a gas. The relationships between the temperature, pressure, and volume of gases have been deduced and expressed in the form of equations known as the gas laws.

All matter is composed of particles (atoms or molecules or mixtures of both) in constant motion. In a gas, the particles are far enough apart and are moving fast enough to escape each other's influence (e.g., attraction or repulsion due to electrical charges). The freely moving particles constantly collide with one another, but the collisions result in no loss of energy. When a gas is cooled, its particles move more slowly, and those that are slow enough to linger in each other's vicinity tend to coalesce because a force of attraction overcomes their lowered kinetic energy. Each particle, when it joins the liquid state with others, gives up a measure of heat called the **latent heat of liquefaction**, but each continues to move at the same speed within the liquid so long as the temperature remains at the condensation point. Warming up a liquid, by contrast, provides constituent particles with **heat of evaporation**, which enables them to escape each other and form the vapour of the liquid, namely, the gaseous state.

Questions...

1. What is a gas?
2. What are the essential differences between gases, liquids and solids?
3. What is the difference between a gas and a vapour?
4. Under what sort of conditions would a gas become liquid? Give examples.

MEASURING HEAT

8

The specific heat, or heat capacity, of a substance is the amount of heat that is required to raise the temperature of a unit weight of the substance by one degree.

The value for specific heat varies widely for different substances. In the metric system the unit of specific heat is the **Calorie**. It is defined as the amount of heat that is required to raise the temperature of one gram of water by one degree Celsius. The specific heat of water is set at 1.000 calorie per gram. All other values are based on this unit.

In the English system of measurements the British Thermal Unit (BTU) is the unit of specific heat. One British thermal unit (252 calories) is the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit. In measuring the heat content of fuels the British thermal unit is the unit of specific heat used.

A measurement of the heat of reaction can be made with an instrument called a calorimeter, a vessel placed in a larger vessel filled with water. This reaction vessel is provided with a sensitive thermometer, and the larger vessel is insulated from the surroundings. A weighed amount of the substance under test is completely burned in the reaction vessel. The rise in temperature of the water is measured. Since the amount of water and the rise in temperature are known, the amount of heat produced can be calculated as the heat of reaction or combustion.

Questions...

1. Why is it important to be able to measure heat accurately?
2. How does measuring the effects of heat vary between solids and liquids?
3. What is a calorie and how does it aid measurement of heat?

EVAPORATION

9

Evaporation is the conversion of a substance from the liquid or solid phase into the gaseous (vapour) phase. If conditions allow the formation of vapour bubbles within a liquid, the vaporization process is called **boiling**. Direct conversion from solid to vapour is called **sublimation**.

Heat must be supplied to a solid or liquid to effect vaporization. The atoms or molecules of a liquid or solid are held together by cohesive forces, and these forces must be overcome in separating the atoms or molecules to form the vapour; the **heat of vaporization** is a direct measure of these cohesive forces.

Condensation of a vapour to form a liquid or a solid is the reverse of vaporization, and in the process heat must be transferred from the condensing vapour to the surroundings. The amount of this heat is characteristic of the substance, and it is numerically the same as the heat of vaporization.

Questions...

1. What is evaporation?
2. List liquids which easily evaporate.
3. How do these differ chemically from liquids which do not easily evaporate?
4. Draw an illustration to show how a liquid evaporates and then condenses and becomes liquid once more.

THERMAL EXPANSION

10

The general increase in the volume of a material as its temperature is increased is called thermal expansion. It is usually expressed as a fractional change in dimensions or volume per unit temperature change;

- a linear expansion coefficient is usually employed in describing the expansion of a solid,
- a volume expansion coefficient is more useful for a liquid or a gas.

If a solid is isometric (has the same structural configuration throughout), the expansion will be uniform in all dimensions. If it is not isometric, there may be different expansion coefficients for different crystallographic directions, and the crystal will change shape as the temperature changes.

Thermal expansion occurs because higher temperatures means that molecules within the object move more rapidly and this causes there to be greater distances between atoms.

Questions...

1. What is thermal expansion?
2. List causes of thermal expansion other than deliberate heating.
3. How does thermal expansion present problems in everyday life? Give examples.
4. Make a list of solids which are very or quite sensitive to thermal expansion, and ones which are not as sensitive.

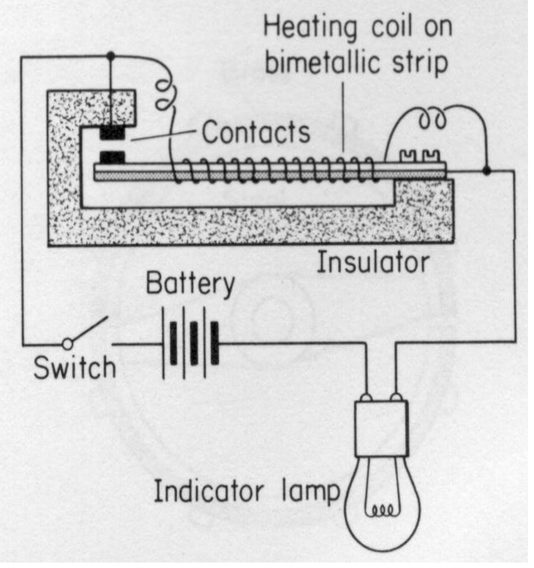
SOLIDS WHICH ARE SENSITIVE TO THERMAL EXPANSION	SOLIDS WHICH ARE NOT AS SENSITIVE TO THERMAL EXPANSION
1.	1.
2.	2.
3.	3.
4.	4.
5.	5.
6.	6.
7.	7.
8.	8.
9.	9.
10.	10.

A THERMOSTAT

This is a device to detect temperature changes for the purpose of maintaining the temperature of an enclosed area constant. In a system including relays, valves, switches, etc., the thermostat generates signals, usually electrical, when the temperature exceeds or falls below the desired value. It usually is used to control the flow of fuel to a burner, of electric current to a heating or cooling unit, or of a heated or cooled gas or liquid into the area it serves. The thermostat is also an element in some types of fire-detection warning systems.

A thermostat is probably easiest understood by studying a central heating system, either in your home or in the school/college which you attend. The thermostat is temperature sensitive and either switches itself on or off depending on the temperature. A thermostat can be set to a particular temperature and can be adjusted up or down as required. If the temperature in the room reaches the desired level the thermostat switch turns off the heating system. When the temperature falls again the thermostat switches on the heating supply again. This means that the temperature can be maintained at a particular level with minimal variation, and also means that fuel is used more efficiently.

One type of thermostat is the bi-metallic strip thermostat. This is simply two strips of metal which react to heat in different ways which are bonded or riveted together. A simple car indicator unit illustrates how it works. A heating coil on the bi-metallic strip heats the strip. When the temperature rises the strip which is more sensitive to heat expands and bends itself whilst the less sensitive metal expands less and is always on the inside of the curve. The bending leads to the strip completing the circuit, and turning the mechanism on. When the mechanism is on the heating coil does not work and so the bi-metallic strip cools off and straightens, breaking the connection again.



Questions...

1. What is a thermostat?
2. Find out and make a list of thermostat controlled appliances in your home or school.
3. Find out about and draw an illustration to show how a thermostat works. Do not use the example shown above.

FISSION

12

Nuclear fission is the break-up of the nucleus of an atom into two lighter nuclei. Occurring mainly in heavy nuclei, this process may take place spontaneously in some cases or may be induced by the excitation of the nucleus with a variety of particles (e.g., neutrons, protons, deuterons, or alpha particles) or with electromagnetic radiation in the form of gamma rays. In the fission process, a large quantity of energy is released, radioactive products are formed, and several neutrons are emitted. These neutrons can induce fission in a nearby nucleus of fissionable material and release more neutrons that can repeat the sequence, causing a chain reaction in which a large number of nuclei undergo fission and an enormous amount of energy is released. If controlled in a nuclear reactor, such a chain reaction can provide power for society's benefit. If uncontrolled, as in the case of the so-called atomic bomb, it can lead to an explosion of awesome destructive force.

The discovery of nuclear fission has opened a new era, the 'Atomic Age.' The potential of nuclear fission for good or evil and the risk/benefit ratio of its applications have not only provided the basis of many sociological, political, economic, and scientific advances but grave concerns as well. Even from a purely scientific perspective, the process of nuclear fission has given rise to many puzzles and complexities, and a complete theoretical explanation is still not at hand.

Questions...

1. What is nuclear fission?
2. What is meant by the 'atomic age'?
3. Why does nuclear fission create so much energy?
4. What are the advantages and disadvantages of creating energy through the use of nuclear fission?

HEAT TRANSFER

There are three modes of heat transfer, which can be described as;

- The transfer of heat by conduction in solids or fluids at rest,
- The transfer of heat by convection in liquids or gases in a state of motion, combining conduction with fluid flow,
- The transfer of heat by radiation, which takes place with no material carrier.

Heat transfer refers to the transfer of heat from one object to another or to the surrounding air, and the method by which this occurs as described in the points above.

The flow of heat in metal bars was studied analytically by the French mathematician Jean-Baptiste-Joseph Fourier and measured by the French physicist Jean-Baptiste Biot in 1816. The conductivity of water was first determined in 1839; the conductivity of gases was not measured until after 1860. Biot formulated the laws of conduction in 1804, and Fourier published a mathematical description of this phenomenon in 1822. In 1803 it was found that infrared rays are reflected and refracted as visible light is, and, after that the study of thermal radiation became part of the study of radiation in general.

Questions...

1. Write a short paragraph explaining what heat transfer means.
2. When is heat transfer useful in our everyday lives? Give examples.
3. When might heat transfer cause problems?
4. Make a list of everyday examples of heat transfer in your home.

EXAMPLES OF HEAT TRANSFER IN MY HOME
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.

HEAT EXCHANGE

These can be any of several devices that transfer heat from a hot to a cold fluid. In many engineering applications it is desirable to increase the temperature of one fluid while cooling another. This double action is economically accomplished by a heat exchanger. Uses include the transfer of heat from metals to water in atomic power plants and the reclaiming of heat energy from the exhaust of a gas turbine by transferring heat to the compressed air on its way to the combustion chambers. Heat exchangers are used extensively in fossil-fuel and nuclear power plants, gas turbines, heating and air-conditioning, refrigeration, and the chemical industry. The devices are given different names when they serve a special purpose. Boilers, evaporators, superheaters, condensers, and coolers may all be considered heat exchangers.

Heat exchangers are manufactured with various flow arrangements and in different designs. Perhaps the simplest is the concentric tube or double-pipe heat exchanger in which one pipe is placed inside another. Inlet and exit ducts are provided for the two fluids. The cold fluid flows through the inner tube and the warm fluid in the same direction through the space between the outer and the inner tube. This flow arrangement is called **parallel flow**. Heat is transferred from the warm fluid through the wall of the inner tube (the so-called heating surface) to the cold fluid. A heat exchanger can also be operated in counterflow, in which the two fluids flow in parallel but opposite directions.

The most common type of heat exchanger is the shell-and-tube type. It utilizes a bundle of tubes through which one of the fluids flows. These tubes are enclosed in a shell with provisions for the other fluid to flow through the spaces between the tubes. In most designs of this type, the free fluid flows roughly perpendicular to the tubes containing the other fluid, in what is known as a cross-flow exchange. In nuclear reactors fuel rods may replace the tubes, and the cooling fluid flowing around the rods removes the heat generated by the fission process.

Questions...

1. What is heat exchange? Write a short paragraph about it.
2. What are the practical uses of heat exchangers in everyday life?
3. Draw a picture of a heat exchanger and label it.

CONVECTION

This is a process by which heat is transferred by movement of a heated fluid such as air or water.

Natural convection results from the tendency of most fluids to expand when heated, i.e., to become less dense and to rise as a result of the increased buoyancy. Circulation caused by this effect accounts for the uniform heating of water in a kettle or air in a heated room: the heated molecules expand the space they move in through increased speed against one another, rise, and then cool and come closer together again, with increase in density and a resultant sinking.

Forced convection involves the transport of fluid by methods other than that resulting from variation of density with temperature. Movement of air by a fan or of water by a pump are examples of forced convection.

Atmospheric convection currents can be set up by local heating effects such as solar radiation (heating and rising) or contact with cold surface masses (cooling and sinking). Such convection currents primarily move vertically and account for many atmospheric phenomena, such as clouds and thunderstorms.

The method of heat transfer called convection depends upon the movement of the material which is heated. It applies to free-moving substances; that is, liquids and gases. The motion is a result of changes of density that accompany the heating process.

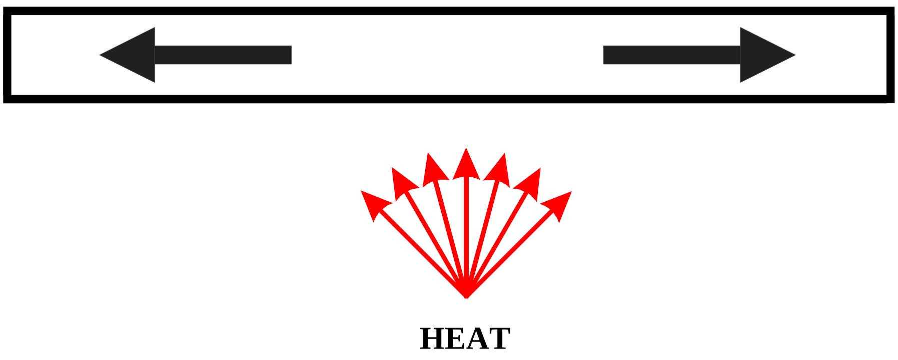
When a liquid or gas is heated, its density (mass per unit volume) decreases; that is, it becomes lighter in weight. A warmer volume of gas will rise while a colder, and thus heavier, volume of gas will descend.

Questions...

1. What is convection?
2. Draw an illustration of a convection heater and show how the heat is transferred.
3. How does convection differ from conduction?

CONDUCTION

Conduction is a point-by-point process of heat transfer. If one part of a body is heated by direct contact with a source of heat, the neighbouring parts become heated successively. If a metal rod is placed in a burner, heat travels along the rod by conduction. This may be explained by the kinetic theory of matter. The molecules of the rod increase their energy of motion. This violent motion is passed along the rod from molecule to molecule.



Questions...

1. What is conduction?
2. How does heat energy spread across a solid object?
3. Why are some solids more heat conductive than others?

LATENT HEAT

This is an amount of energy absorbed or released by a substance during a change in its physical state that occurs without changing its temperature.

- The latent heat associated with melting a solid or freezing a liquid is called the heat of fusion,
- that associated with vaporizing a liquid or a solid or condensing a vapour is called the heat of vaporization.

For example, when a pot of water is kept boiling, the temperature remains at 100^0 C (212^0 F) until the last drop evaporates, because all the heat being added to the liquid is absorbed as latent heat of vaporization and carried away by the escaping vapour molecules. Similarly, while ice melts it remains at 0^0 C (32 F), and the liquid water that is formed with the latent heat of fusion is also at 0^0C.

The structure of a solid is maintained by forces of attraction between the individual molecules or ions which move slightly in relation to each other. When heat is absorbed, these motions increase until at the melting point the attractive forces can no longer preserve the orderly arrangement, and the solid changes into a liquid, in which the individual particles move about independently, attracted to each other by forces which are much weaker. When a substance is heated sufficiently, even the weak forces that hold the particles together in the liquid state are overcome, and at the boiling point the liquid transforms into vapour.

Latent heat is associated with processes other than changes between solid, liquid, and vapour phases of a single substance. The process of dissolving one substance in another often involves heat; if the solution process is a strictly physical change, the heat is a latent heat. Sometimes, however, the process is accompanied by a chemical change, and part of the heat is that associated with the chemical reaction.

Questions...

1. What does 'latent' mean?
2. What is the difference between latent heat and heat created by chemical reactions?

ASSIGNMENT - HOT AND COLD COUNTRIES

Physics is not just about experiments in the classroom; there are many practical examples of how heat affects people in their everyday lives, and how they adapt to cope with the conditions which prevail. This assignment asks you to choose two countries, one hot and one cold, (e.g. India and Norway; do not necessarily use this example). Selecting specific aspects of everyday life, find out and write about how different climates affect the way people work and live. Consider the pointers below:

- The types of houses built,
- The types of clothing worn,
- Where populations choose to live,
- Adaptations to vehicles, machinery,
- Types of production.

ASSIGNMENT - HEAT CONSERVATION

Heat conservation is very important because efficient use of energy means that natural resources will last longer, there is less pollution, and money is saved, among other factors. This assignment asks you to use your knowledge of how heat works, and how it can be used, to design a house which is very heat efficient. Draw a picture of your house and label it showing how improvements help to conserve heat. The pointers below might be helpful:

- Use of renewable sources of energy,
- Use of insulating materials,
- Lagging,
- Special design features which encourage minimum heat usage,
- Combining different types of heating,
- Choosing cheaper fuels,
- Choosing more efficient fuels,
- Experimenting with convection and conduction,
- More efficient use of thermostats.

ASSIGNMENT - SOURCES OF HEAT ENERGY

This assignment asks you to find out about energy sources for the future. Assuming that natural fossil fuels like coal and gas will run out sometime in the future you have to find out about other energy sources. You must also write about how viable these sources might be and what needs to be done to make these energy sources easy and practical to use. Find out about types of energy including:

- Wind energy,
- Water energy,
- Nuclear energy,
- The Sun's energy,
- Recycling rubbish to generate energy.

When you have completed your investigations write a final report on what you have found and your recommendations for viable future energy sources.

REPORT ON NEW ENERGY SOURCES