HEAT AND ENERGY

2. Heat, Phase Changes and Heat Transfer

Preview:

In this second part of the course we will

- revisit the concept of heat, and define its units
- describe what is meant by sensible heat, and latent heat
- discuss phase changes and phase diagrams
- define specific heat capacity, and latent heat capacity
- discuss calorimetry: an experimental technique to measure thermal constants such as the specific heat capacity
- discuss differences and characteristics of the three methods of heat transfer: conduction, convection and radiation
- describe practical and environmental applications of heat transfer, including the greenhouse effect

2.1 Units of Heat

Objectives:

To be able to

- define and distinguish between various units of heat
- define the mechanical equivalent of heat

- Heat describes a type of *energy transfer*, in particular the addition or removal of internal energy to a body or system.
- Heat is energy in transit, and is measurable as an energy loss or gain.
- Heat is described by standard energy units.
- **The SI unit is the joule (J), or newton-metre (Nm).**
- Before scientists realized that heat is transferred energy, heat was measured in terms of its ability to raise the temperature of water.
- **Thus, another commonly used unit of heat is the *kilocalorie* (kcal):**

  One kilocalorie (kcal) is defined as the amount of heat needed to raise the temperature of 1 kg of water $1\ \mathrm{C}^0$ *(from* $14.5^0\mathrm{C}$ *to* $15.5^0\mathrm{C}$*).*[1]
- A smaller unit, **the *calorie* (cal)** is also sometimes used:

  One calorie is the amount of heat needed to raise the temperature of 1 g of water by $1\ \mathrm{C}^0$ *(from* $14.5^0\mathrm{C}$ *to* $15.5^0\mathrm{C}$*).*
- A familiar use of the larger kilocalorie is to specify the energy value of food; in this context the word is usually shortened to *Calorie* (Cal).
- **A capital 'C' is used to distinguish the larger kilogramme-Calorie, or kilocalorie, from the smaller gramme-calorie; they are sometimes referred to as the 'big Calorie' and the 'little calorie'.**
- A unit of heat commonly used in industry is the *British thermal unit* (Btu):

  One Btu is the amount of heat needed to raise the temperature of 1 lb of water by $1\ \mathrm{F}^0$ *(from* $63^0\mathrm{F}$ *to* $64^0\mathrm{F}$*).*

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[1] The temperature range is specified because the energy needed to raise 1 kg of water by $1\ \mathrm{C}^0$ varies slightly with temperature (at a pressure of 1 atm, it is a minimum in the specified range).

The Mechanical Equivalent of Heat

- The English scientist James Joule was able to verify quantitatively that water can be heated by doing mechanical work.
- Using his apparatus, Joule demonstrated that when a given amount of mechanical work was done, the water was heated, as indicated by an increase in temperature.
- Joule's experiment demonstrated that for every 4186 J of work done, the temperature of water rose $1\ \mathrm{C}^0$ per kg.
- **This relationship is called the *mechanical equivalent of heat*, and provides a conversion factor between kilocalories and joules:**

$$1 \text{ cal} = 4.186 \text{ J.}$$

- The relations among the various heat units are:

$$1 \text{ cal} = 10^{-3} \text{ Cal} = 10^{-3} \text{ kcal} = 3.969\times10^{-3} \text{ Btu} = 4.186 \text{ J.}$$

2.2 Sensible Heat

Objectives:

To be able to

- describe what is meant by 'sensible heat'
- define specific heat
- explain how the specific heat capacities of materials are obtained using calorimetry

- ***Sensible heat*** **refers to heat which brings about a change in the body which can be detected by the senses; this implies it causes the temperature of the body to change.**
- **Thus, sensible heat, Q, can be sensed by humans. It is that portion of the total internal energy associated with a temperature change ΔT.**
- Some materials heat up more easily than others. The change in temperature depends on the energy supplied to the object, the mass of the object, and the nature of the substance.
- When heat is added to a substance, the energy may go to increase the random molecular motion (which results in a temperature change), and also to increase the potential energy associated with the molecular bonds.
- Different substances have different molecular configurations and bonding.
- Thus, if equal amounts of heat are added to equal masses of different substances, the resulting temperature changes will not generally be the same.
- **The heat, Q, can be measured as the product of the change of temperature, ΔT, and a quantity called the heat capacity, C:**[2]

$$Q = C\Delta T.$$

- **The SI unit of heat capacity, C, is J/K.**
- **The amount of sensible heat, Q, needed to change the temperature of a unit mass of substance is given by:**

$$\frac{Q}{m} = c\Delta T,$$

where m is the mass of the substance, and c is a quantity called the *specific heat capacity*, or simply the *specific heat*.

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[2] The word capacity in this context may be misleading: you should not think of an object as 'containing' heat or being limited in its ability to absorb heat. Heat transfer can proceed without limit as long as a temperature difference is maintained.

Specific Heat Capacity

- The word *specific* is a term often used to indicate that the property relates to unit mass of the substance involved.
- **The <u>specific heat capacity</u> is the amount of energy required to raise the temperature of 1 kg (unit mass) of a substance by $1\ \mathrm{C}^0$.**
- **The specific heat capacity, c, is therefore defined as the heat capacity C per unit mass**.
- The specific heat capacity is *characteristic of*, or *specific for*, a given substance, and gives an indication of its internal molecular configuration and bonding.
- The specific heat capacity is given by

$$c = \frac{Q}{m\Delta T}.$$

- **The SI units of specific heat capacity are: J/(kg K).**
- **Another way of stating this is that the heat needed to raise the temperature of an object of mass m by ΔT is given by:**

$$Q = mc\Delta T.$$

- Specific heat capacity depends somewhat on temperature (and pressure), but over usual temperature intervals these variations can be neglected and c can be considered constant.
- **The greater the specific heat capacity of a substance, the more energy must be transferred to it or taken from it to change the temperature of a given mass of it.**
- A substance with a greater heat capacity has a greater *heat capacity*, i.e., it accepts or yields more heat for a given temperature change and mass.
- **<u>Water</u> has a relatively large specific heat capacity**.
- *Everyday examples of this*: burning your mouth on a baked potato or cheese of a pizza.
- Note: In determining and then using the specific heat of any substance, we need to know the conditions under which heat transfer occurs.
  For solids and liquids, it turns out that the specific heats under constant pressure and constant volume differ usually by no more than a few percent.
  Gases have quite different values for their specific heats under constant-pressure conditions and under constant-volume conditions.

Calorimetry (The Method of Mixtures)

- ***<u>Calorimetry</u>* is the experimental technique to measure the values of thermal constants, such as the specific heat capacity.**
- Such measurements usually necessitate the determination of a quantity of heat, for example by observing the rise in temperature it produces in a known quantity of water, or other suitable liquid.
- **A *<u>calorimeter</u>* is a vessel containing the liquid used in calorimetry**. The name is also sometimes used for the entire apparatus used in measuring thermal quantities.
- The specific heat capacity of a substance is determined by measuring the quantities on the right-hand side of the heat equation:

$$c = \frac{Q}{m\Delta T}.$$

- **Basically, heat exchange problems are just a matter of 'thermal accounting': If something loses heat, something else must gain heat, or else the energy conservation principle would be violated.**

2.3 Latent Heat & Phase Changes

Objectives:

To be able to
- compare and contrast the three common phases of matter
- relate latent heat to phase changes

- ***Latent heat*** **is a 'hidden' heat, not evident until a substance undergoes a phase change**.
- *Example*: Evaporation of liquid water droplets cools the air by removing sensible heat and storing it as latent heat.

Phases of Matter

- Matter normally exists in one of three *phases*: solid, liquid and gas (although plasma is often considered a fourth state of matter).
- The phase that matter is in depends on its internal energy (as indicated by its temperature) and the pressure on it.
- In the *solid phase*, molecules are held together by attractive forces, or bonds.
- Adding heat causes increased motion about the molecular equilibrium positions.
- If enough heat is added to break the inter-molecular bonds, the solid undergoes a *phase change* and becomes a liquid.
- The temperature at which a solid undergoes a phase change to become a liquid is called the *melting point*.
- Conversely, the temperature at which a liquid becomes a solid is called the *freezing point*.
- In the *liquid phase*, molecules of a substance are relatively free to move, and a liquid assumes the shape of its container.
- In certain liquids, there may be some ordered structure, giving rise to so-called liquid crystals, as used in LCD's (liquid crystal displays) in calculators, watches, clocks etc.
- Adding heat increases the motion of the molecules of a liquid.
- When the molecules have enough energy to become separated by large distances (compared to their diameters), the liquid changes to the *gaseous phase*, or *vapour phase*. (A gas has the property that it fills the container it is kept in.)
- This change may occur slowly by the process of *evaporation*, or rapidly at a particular temperature called the *boiling point*.
- Conversely, the temperature at which a gas *condenses* and becomes a liquid is called the *condensation point*.
- Some solids (such as dry ice, i.e., carbon dioxide) change directly from the solid to the gaseous phase. This process is called *sublimation*.
- Conversely, a phase change from a gas to a solid is called *deposition*.
- **The following phase changes require the supply of heat:**
  - ***vaporization*: liquid → vapour**
  - ***melting*: solid → liquid**
  - ***sublimation*: solid → vapour**
- **The following phase changes release heat to the surroundings:**
  - ***condensation*: *vapour* → liquid**
  - ***fusion*: liquid → *solid***
  - ***deposition*: vapour → solid**

Latent Heat

- In general, when heat energy is transferred to a substance, its temperature increases.
- When added (or removed) heat causes only a phase change, the temperature of the substance does *not* change.
- During a phase change, the heat energy goes into the work of breaking bonds and separating molecules, rather than increasing the temperature.
- The amount of heat per unit mass that must be transformed when a sample completely undergoes a phase change is called the *latent heat*.
- The heat involved in a phase change, the *latent heat*, L, is given by

$$L \equiv \frac{Q}{m},$$

where m is the mass of the substance.
- The latent heat L has units of J/kg.
- **The latent heat for a liquid-solid phase change is called the *latent heat of fusion*, L_f, also referred to as <u>the *heat of fusion*</u>.**
- **The latent heat for a liquid-gas phase change is called the *latent heat of vaporization*, L_v, also referred to as the <u>*heat of vaporization*</u>.**
- **The latent heat for the less common solid-gas phase change is called the <u>*latent heat of sublimation*</u>, L_s.**
- The values of the latent heats for water are:

$$\begin{aligned} L_v &= \pm 22.6\times10^5 \text{ J/kg} \quad \text{condensation/vaporization} \\ L_f &= \pm 3.33\times10^5 \text{ J/kg} \quad \text{fusion/melting} \\ L_d &= \pm 28.3\times10^5 \text{ J/kg} \quad \text{deposition/sublimation} \end{aligned}$$

where the sign depends on the direction of the phase change.
- The latent heat of vaporization is therefore almost 7 times the latent heat of fusion; this indicates more energy is needed to separate the molecules in going from water to steam than to break up the lattice structure in going from ice to water.
- The word 'latent' means hidden. In this context, it can be understood by considering a situation involving the human skin.
  - To convert 1 kg of water into steam requires 540 kcal of energy, and conversely, when 1 kg of steam condenses into water, this amount of energy is released.
  - As a result, burns from steam are usually more serious than those from boiling water.
  - The condensing of steam on the skin provides an additional 540 kcal/kg of heat, that is seemingly hidden until contact.

Phase Diagrams

- Information about phase changes is represented on graphs called *phase diagrams*.
  - One example is the pT (pressure-temperature) diagram for water.
  - The curves are formed of the points (p,T), or the pressure-temperature combinations at which different phases are in equilibrium.
  - Example: the point at 1 atm and 100^0 C corresponds to the normal boiling point, at which liquid water and steam are in equilibrium.
- **The <u>*triple point*</u> is the point at which all three phases coexist**.
- This is the unique point used as a reference point (in the case of water) for the Kelvin scale.
- The three curves branching out from this point separate the *phase regions*:
  - the *fusion curve* separates the solid and liquid phase regions;
  - the *vaporization curve* separates the liquid and gaseous phase regions;
  - the *sublimation curve* separates the solid and gaseous phase regions.
- *Vapour* is another term commonly used for *gas*.

- *Water vapour* is water in the gas phase (vapour is also used in a non-technical sense to mean visible droplets of water, such as condensed steam or clouds).
- The distinction between vapour and gas is often made relative to the critical point at the end of the vaporization curve.
- At temperatures less than the critical temperature (374^0 C for water), a gas will change to a liquid if sufficient pressure is applied.
- If a gas is above its critical temperature, no amount of pressure will cause it to become a liquid: it becomes denser and denser with increasing pressure, but never quite becomes a liquid.
- A substance that is gaseous and has a temperature above its critical temperature is called a *gas*, and a substance that is gaseous but with a temperature below its critical temperature is known as a *vapour*.

2.4 Methods of Heat Transfer

Objectives:

To be able to

- describe the three methods of heat transfer
- give practical/environmental examples of each
- define a blackbody

Conduction

- The process of *heat conduction* is visualized as resulting from molecular interactions (interactions/collisions between electrons and molecules):
- **Transfer of heat through contact of solid substances is called <u>conduction</u>**
  - Molecules in one part of a body at higher temperature vibrate faster. They collide with and transfer some of their energy to less energetic molecules located toward the cooler part of the body. In this way energy is conductively transferred from a higher-temperature region to a lower-temperature region - transfer as a result of a temperature difference.
- *Thermal conductors* are materials that are good conductors of heat.
- Metals (a type of solid) are thermal conductors. *Why*?
  - A metal has a large number of electrons that are free to move around (*conduction electrons*), and are not permanently bound to any particular atom or molecule. The free electrons are believed to be primarily responsible for the heat conduction of metals.
- *Thermal insulators* are materials that are poor conductors of heat.
- Non-metals such as wood or cloth are thermal insulators. *Why*?
- In general, the ability of a substance to conduct heat depends on its phase.
  - Gases are poor thermal conductors because their molecules are relatively far apart, and collisions are therefore infrequent.
  - Liquids are better thermal conductors than gases because their molecules are closer together and can interact more readily.
  - Non-metals have relatively few free electrons.

Convection

- **Transfer of heat due to the movement of fluid substances is called <u>convection.</u>**
- The mobility of molecules in fluids permits heat transfer by another process - convection.
- Heat transfer by *convection* involves mass transfer.
- Example: cold water in contact with a hot object, such as the bottom of a pot.

- *Natural convection cycles* occur in liquids and gases.
- Convection can also be *forced*, which means that the medium of heat transfer is moved mechanically.
- In this case, heat can be transferred in the absence of a temperature difference, and even from a low-temperature region to high-temperature one.
- *Examples of Natural Convection*:
  - Atmospheric processes: During the day, the ground heats up more quickly than do large bodies of water; this occurs because water has a larger specific heat capacity, and because mixing currents disperse the absorbed heat throughout the large volume of water. The air in contact with the warm ground is heated by conduction. That air expands, becoming less dense than the surrounding cooler air. As a result, the warm air rises (air currents) and other air moves horizontally (winds) to fill the space - creating sea breeze near a large body of water. Cooler air descends, and a thermal convection cycle is set up, which transfers heat away from the land. At night, the ground loses its heat more quickly, and the water surface is warmer than the land. As a result, the cycle is reversed.
  - You can see convection currents in the air above a hot road surface in the summer and in transparent liquids, such as heated water in a glass container. This is because regions of different temperatures have different densities, which cause a bending, or refraction, of light.
  - Atmospheric convection plays a fundamental role in determining global climate patterns and daily weather variations.
  - Glider pilots and birds alike seek rising thermals (currents of warm air) that keep them aloft.
  - Huge energy transfers take place within the oceans by the same process.
  - Energy is transported to the surface of the Sun from the nuclear furnace at its core by enormous convection cells, in which hot gas rises to the surface along the cell core and cooler gas around the core descends below the surface.
- *Examples of Forced Convection*:
  - Energy transfer from a low-temperature region to a high-temperature one occurs in the case of a refrigerator coolant removing energy from the inside of the refrigerator. The circulating coolant carries heat energy from the inside of the refrigerator, and this heat is given up to the environment.
  - Forced-air heating systems in homes.
  - The human circulatory system: The human body does not use all of the energy obtained from food; a great deal is lost. So that body temperature will stay normal, the internally generated heat energy is transferred close to the surface by blood circulation. From the skin, it is conducted to the air or lost by radiation.
  - The cooling system of a car engine: Water or some other coolant is circulated (pumped) through most car cooling systems (some engines are air-cooled). The fluid medium carries heat to the radiator (a heat exchanger), where forced air flow produced by the fan carries it away. The radiation of a car is actually misnamed - most of the heat is transferred from it by convection rather than radiation.

Radiation

- **Transfer of heat by radiation or light is called <u>radiation</u>.**
- *Radiation*, which is a mechanism for heat transfer by electromagnetic waves, does not need a medium for transport.
- Heat transferred in this way is often called *thermal radiation*, to distinguish it from electromagnetic *signals* (like in TV broadcasts) and from nuclear radiation (energy and particles emitted by nuclei).
- The word 'radiate' generally means to emit.
- Infrared radiation is sometimes referred to as 'heat rays'.
- All objects whose temperatures are above 0 K emit radiation (including people).
- Dark surfaces are not only better emitters of radiation, they are also good *absorbers*.

- Shiny surfaces are poor absorbers, since most of the incident radiation is reflected (hence, it is better to wear light-coloured clothes in the summer, and dark-coloured clothes in the winter).
- In general, *a good emitter is also a good absorber*.
- An ideal, or perfect, absorber (and emitter) is referred to as a *blackbody* ($\varepsilon = 1$).
- When an object is in *thermal equilibrium* with its surroundings (environment), its temperature is constant: it emits and absorbs radiation at the same rate.

Applications

- Heat is transferred from the Sun to the Earth through (nearly) empty space by means of electromagnetic waves.
- If you stand near an open fire, you can feel the heat on your exposed hands and face. The heat transfer is not due to convection or conduction, since heated air rises and air is a poor conductor. Visible radiation is emitted from the burning material, but most of the heating effect comes from the *invisible infrared radiation* emitted by the glowing ember or coals. You feel this radiation because it is absorbed by water molecules in your skin (body tissues is about 85% water). The water molecule has an internal vibration whose frequency coincides with that of infrared radiation, which is therefore absorbed readily. [This is called *resonance absorption*. The electromagnetic wave drives the molecular vibration, and energy is transferred to the molecule, somewhat like pushing a swing.]
- Red infrared lamps are used to keep food warm in cafeterias.
- Although infrared radiation is invisible to the human eye, it can be detected by other means. The frequency of infrared radiation is proportional to the temperature of its source. This is the basis for infrared thermometers, which, using infrared detectors, can measure temperature remotely. Also, you can buy special infrared film for some cameras. A picture taken with this film will be an image consisting of contrasting light and dark areas corresponding to regions of higher and lower temperatures. Special instruments that apply such thermography are used in industry and medicine.
- A new application of thermograms is for security. The system consists of an infrared camera and a computer that identifies people by means of the heat patterns emitted by the facial blood vessels. The camera takes a picture of the radiation from a person's face, which is compared with an earlier image stored in the computer memory. It is reported that the system can even distinguish between identical twins, whose facial features are slightly different. Also, changes in body temperature from weather conditions or a fever do not affect the identification, as the relative patterns of radiation remain the same.
- <u>The Greenhouse Effect</u>: The greenhouse effect is one of the factors which regulate the Earth's long-term average temperature, which has been fairly constant. A portion of the solar radiation we receive reaches the Earth's surface and warms it. The Earth in turn reradiates energy in the form of infrared radiation. The balance between absorption and emission of radiation is the major factor in stabilizing the Earth's temperature.

  It is this balance that is affected by the concentration of *greenhouse gases* - primarily water vapour and CO_2 (carbon dioxide) - in the atmosphere. As the infrared radiation passes through the atmosphere, some of it is absorbed by the greenhouse gases. These gases are *selective absorbers*: they absorb radiation at some wavelengths, but not at others.

  If terrestrial infrared radiation is absorbed, the atmosphere warms, warming the Earth (heat transfer by radiation). This rise in surface temperature causes a shift in the wavelength of the emitted radiation. The wavelength is eventually shifted to a 'window' in the absorption spectrum where little or no absorption takes place, and the terrestrial radiation passes through the atmosphere and into space. Thus, the Earth loses energy and its surface temperature decreases. But with a temperature decrease, the terrestrial radiation shifts to a longer wavelength and is again absorbed by the greenhouse gases. We have a turning on and off, so to speak, similar to the action of a thermostat. Hence, the selective absorption of atmospheric gases play an important role in maintaining the Earth's average temperature.

The phenomenon is called the atmospheric greenhouse effect because the atmosphere functions a bit like the glass in a greenhouse: the absorption and transmission properties of glass are similar to those of the atmospheric greenhouse gases - in general, visible radiation is transmitted, but infrared radiation is selectively absorbed. Most of us can remember the warming effect of sunlight passing through glass, for example, in a closed car on a sunny, cold day. Similarly, a greenhouse heats up by absorbing sunlight and trapping the reradiated infrared radiation. Thus, it is quite warm inside on a sunny day, even in winter. (But in practice, the elimination of heat loss by convection is the chief factor in maintaining an elevated temperature: the glass enclosure keeps warm air from escaping upward, as it normally would. The temperature of a greenhouse in summer is controlled by painting the glass panels white so that some of the sunlight is reflected, and opening panels to let some hot air escape.)

A recent concern is that human activities may accentuate the greenhouse warming: the so-called enhanced greenhouse effect. With all the combustion of fossil fuels for heating and industrial processes, and deforestation, vast amounts of CO_2 and other greenhouse gases are vented into the atmosphere. There is a worry that the result of this trend will be global warming: an increase in the Earth's average temperature that could dramatically affect the environment. For example, the climate in many parts of the globe might be altered, with effects on agricultural production and world food supplies that are very difficult to predict. It has also been suggested that a general rise in temperature might cause partial melting of the polar ice caps. Sea levels would rise, flooding low-lying regions and endangering coastal ports and population centres.

An interesting sidelight to the greenhouse effect concerns the transmission of radiation through glass. In an actual greenhouse, the visible portion of the sunlight is transmitted through the glass, but the short-wavelength ultraviolet radiation is absorbed. The ultraviolet spectrum from 280 to 400 nm is divided into two regions called UVA (320-400 nm) and UVB (280-320 nm). Ordinary window glass does not appreciably transmit UVB radiation, which is the primary cause of suntan and sunburn. Hence, although a considerable warming effect occurs through glass from visible radiation, people do not receive a tan or severe sunburn through ordinary window glass because of UVB absorption. Some slight reddening may occur for sensitive skin from the UVA radiation that is transmitted.

- <u>The Microwave Oven</u>: The microwave oven is a common kitchen appliance which is both time-saving and energy-saving, since the oven doesn't have to be warmed up like a conventional oven. The principle of operation of the microwave oven is heat transfer by radiation.

  Microwaves are a form of electromagnetic radiation; they have a frequency range just below that of infrared radiation. Like infrared radiation, microwaves are absorbed mainly by water molecules (in a molecular resonance). In a microwave oven, the microwaves are generated electronically and distributed by reflection from a metal stirrer or fan and the metal walls. Because the walls reflect the radiant energy, they do not get hot.

  Microwaves pass through plastic wrap, glass, or dishes made of other 'microwave-safe' materials and are absorbed by water molecules in the food, producing rapid heating. (Metal utensils or objects cannot be used in microwave ovens because the microwaves can dislodge electrons from metals, cause sparking and possibly damage.) The microwaves do not penetrate the food completely but are absorbed near the surface. Heat is then conducted to the interior of the food, just as it is in conventional oven heating. This is why it is advisable to let large items or portions sit for a time after the microwave oven has shut off, so that they will be warmed or cooked throughout.

  Since microwaves could be absorbed by water molecules in the skin, causing burns, microwave ovens have several important safety features. The door is tight-fitting so that microwaves cannot leak out. The glass in the door is fitted with a metal shield that has small holes through which food can be viewed without opening the door. Microwaves are reflected by this shield and prevented from coming through the glass (essentially, the waves are larger than the holes.) Also, there is a mechanism that automatically shuts off the oven when the door is opened, so a person cannot get into the oven while it is running. In fact, the oven cannot be turned on when the door is open.

- Body Heat: See Exercise Class.

- The Thermos Flask: The thermos bottle, sometimes called a *Dewar flask*, is designed to minimise heat transfer by conduction, convection and radiation. It is used to store either hot or cold liquids for long periods of time. The standard vessel is double-walled Pyrex glass with a silvered inner wall. The space between the walls is evacuated to minimise heat transfer by conduction and convection. By reflecting most of the radiant heat, the silvered surface minimizes heat transfer by radiation. Very little heat is lost through the neck of the flask because Pyrex glass is a poor conductor. A further reduction in heat loss is achieved by reducing the size of the neck. A common scientific application of Dewar flasks is storage of liquid nitrogen (boiling point 77K) and liquid oxygen (boiling point 90K). For substances that have very low specific heats, such as liquid helium (boiling point 4.2K), it is often necessary to use a double Dewar system in which the Dewar flask containing the liquid is surrounded by a second Dewar flask. The space between the two flasks is filled with liquid nitrogen.

  Some of the principles of the Dewar flask are used in the protection of sensitive electronic instruments in orbiting space satellites. In half of its orbit around the Earth, a satellite is exposed to intense radiation from the Sun, and in the other half it is in the Earth's cold shadow. Without protection, its interior would thus be subjected to tremendous extremes of heating and cooling. The interior of the satellite is wrapped with blankets of highly reflective aluminium foil. The foil's shiny surface reflects away much of the Sun's radiation while the satellite is in the unshaded part of the orbit, and helps retain interior heat while the satellite is in the Earth's shadow.

  Wool sweaters and down jackets keep us warm by trapping the warmer air in regions close to our bodies and hence reducing heat loss by convection and conduction. In other words, what keeps us warm is not the clothing itself but the air trapped in the clothing.

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