UNIT

5

Heat

LEAD-IN

1 **Working in groups of three or four, state whether the following sentences are *true* or *false*, and correct the false ones.**

1 The amount of heat needed to raise 1 m^3 of water by 1 °C is 4,186,000 J. T F

2 Raising the temperature of a block of gold by 1 °C and raising the temperature of a block of aluminium by 1 °C requires a very different amount of heat. T F

3 An aluminium pot (mass = 1 kg) filled with 1 L (litre) of water absorbs 100 J of energy. The temperature of the pot will be higher than the temperature of the water. T F

2 **Match the terms (1-6) to their corresponding definitions (a-f).**

- ☐ 1 British thermal unit
- ☐ 2 Heat
- ☐ 3 Specific Heat
- ☐ 4 calorie
- ☐ 5 Heat Capacity
- ☐ 6 Internal Energy

a The quantity of heat required to raise a unit mass of material by one degree in temperature.

b A kind of energy that excludes the potential or kinetic energy of the system as a whole.

c Energy in transit between a system and its surroundings when they are at different temperatures.

d The heat required to raise a system by 1 °C in temperature.

e The amount of energy transfer required to raise the temperature of 1 lb of water from 63 °F to 64 °F.

f The amount of energy transfer necessary to raise the temperature of 1 g of water from 14.5 °C to 15.5 °C.

READING AND LISTENING

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An Introduction to Heat

LISTENING ACTIVITY

With your partner, consider the gaps in the text to the right. Try to put the right word in each gap. When you have finished, listen to the text to check your answers. Were they correct?

betweeen	make	fridge	energy	temperature
end	increase	plus	associated	potential

Internal energy is the total [1] .... associated with atoms and molecules (microscopic components) that a system possesses. It includes the [2] .... energy between molecules as well as the kinetic energy of random translational, rotational, and vibrational molecular motion, but it does not include the bulk kinetic energy associated with the motion of the whole system. Internal energy is thermal energy [3] .... bond energy. The former is the part of

internal energy [4] .... with the random motion of molecules, and it is related to temperature: an [5] .... in energy always corresponds to an increase in thermal energy and vice-versa. Bond energy, by contrast, is the potential energy that exists [6] .... molecules.
For this reason, even though internal energy is related to temperature, their relationship is limited: it's possible for a change in internal energy levels to occur in the absence of any temperature variation. This happens, for example, during the formation of ice or the condensation of vapour. The [7] .... of these systems remains constant until the [8] .... of the process.
The everyday use of the word "heat" isn't often scientifically precise: in everyday terms, you heat a kettle of water to [9] .... tea, you cool drinks in the [10] .... , the Sun heats the Earth, that heat flows from the stove into a pot of soup. The correct way to define **heat** is as **energy in transfer between a system and its surroundings when they are at different temperatures.** It also covers two systems or two parts of a body or system that are at different temperatures.

COMPREHENSION QUESTIONS 1

Answer the following questions.

1 Does the motion of a thrown brick modify its internal energy?
2 What's the difference between bond energy and thermal energy?
3 How is the scientific definition of heat different to the non-scientific one?

Defining Heat

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The second law of thermodynamics states that:

> heat always flows spontaneously from a body at a higher temperature to a body at lower temperature.

A body never *possesses* heat: it can possess energy, but heat is energy in transit by definition.
When you heat a substance, you are transferring energy to it by placing it in contact with surroundings that are at a higher temperature. This is the case, for example, when you put a pan of cold water on a stove burner: the burner is at a higher temperature than the water, so the water gains energy. The term 'heat' is also used for the amount of energy transferred by this method.
An 18th century model of heat pictured heat flow as the movement of a hypothetical fluid called "*caloric*". However, the caloric fluid was never detected or measured. In the 19th century, this interpretative model was abandoned and the new definition appeared. Scientists use the internationally accepted unit of energy, the **joule** (**J**), to describe thermal processes. Earlier studies used another unit to measure thermal processes, the name of which is reminiscent of *caloric*: the **calorie** (**cal**), defined as the amount of energy transfer necessary to raise the temperature of 1 g of water from 14.5 °C to 15.5 °C. Nutritionists, when describing the energy content of food, usually measure in kcal (=1,000 cal), but very often use a different measure: the "Calorie" with a capital 'C', which is the same as 1 kcal.
The standard unit of energy in the U.S. system is the British thermal unit (**Btu**), defined as the amount of energy transfer required to raise the temperature of 1 lb (1 pound = 0.45 kg) of water from 63 °F to 64 °F.

COMPREHENSION QUESTIONS 2

Answer the following questions.

1 Why can't a body possess heat?
2 How is the caloric different to a modern understanding of heat?
3 What's the difference between a calorie and a Calorie?
4 A body is at a constant temperature. Can you say for sure that it isn't being heated? Why, or why not?
5 When you heat a body, does it possess more heat than before?

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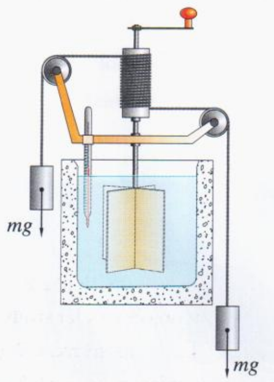
Heat Capacity and Specific Heat

JAMES PRESCOTT JOULE
(1818-1889)

Joule demonstrated that heat and work (mechanical, electrical etc.) are both kinds of energy transfer. In Joule's experiment the system consists of water in a thermally insulated container. Work is done on the water by a rotating paddle wheel, which is driven by heavy blocks falling downwards. The temperature of the stirred water increases due to the friction between it and the paddles. By varying the conditions of the experiment, Joule found that the loss in mechanical energy is proportional to the increase in water temperature ΔT, and the proportionality constant was found to be approximately 4.186. This is the amount of work required to produce a unit of energy and is known as the **mechanical equivalent of heat**.
So: 1 cal = 4.186 J



↑ Schematic diagram of Joule's experimental apparatus.

When energy is added to a system and there is no change in the kinetic or potential energy of the whole system, the temperature of the system usually rises.
The quantity of energy required to raise the temperature of a given mass of a substance by a certain amount varies from one substance to another. For example, the quantity of energy required to raise the temperature of 1 kg of water by 1 °C is 4186 J, but the quantity of energy required to raise the temperature of 1 kg of ice is 2096 J. 1 kg of silver requires 234 J, and only 129 J are needed to increase the temperature of a kilogram of gold by 1 °C.
The amount of energy required to raise the temperature of a particular sample of a substance by 1 °C is known as the substance's **heat capacity (C)**:

$$C = \frac{Q}{\Delta T} \qquad (5.1)$$

where C represents heat capacity, Q is the heat provided, and ΔT is the temperature difference between the final temperature of the system T_f and its initial temperature T_i ($\Delta T = T_f - T_i$).
The units of heat capacity are J/°C or J/K when using kelvin as units of temperature.
This amount of energy required depends on the substance in question, but for any given substance it also varies with quantity. For this reason, heat capacity C is an extensive property (i.e. a property that depends on the size of the system or its total mass). Obviously, you have to spend a much larger quantity of energy in raising the temperature of a full swimming pool than you do to raise the temperature of a cup of water in the same ΔT.
As it is preferable to work with intensive properties of matter (i.e. properties that aren't dependent on the system's size or total mass), *specific heat 'c'* is scientifically convenient:

$$c = \frac{C}{m} \qquad (5.2)$$

where c indicates specific heat, C is heat capacity and m is the mass of the system. Specific heat is heat capacity per unit mass, and therefore its units are:

$$\frac{\text{j}}{\text{Kg °C}} \quad \text{or} \quad \frac{\text{j}}{\text{Kg K}}$$

Substance	Specific heat [J/(kg K)	Specific heat [cal/(g °C)]
Aluminium	900	0.215
Gold	129	0.030
Iron	450	0.11
Silver	234	0.056
Brass	394	0.095
Lead	129.8	0.031
Ice (-5 °C)	2096	0.5
Water (15 °C)	4186	1
Mercury	140	0.033
Alcohol (Ethyl)	2400	0.58
Steam (100 °C)	2010	0.48
An average human body	3470	0.83

The table to the left indicates the specific heat values for some substances measured in J/(kg K) and in cal/(g °C). The reason why the cal unit is often used, even though it is obsolete, is that it simplifies thermal calculations involving water: the specific heat of water at 15 °C is **1** cal/(g °C).

The most common equation in thermal problems can be derived from the definition of heat capacity:

$$C = \frac{Q}{\Delta T} \rightarrow Q = C \cdot \Delta T$$

or substituting $\Delta T = T_f - T_i$:

$$Q = C \cdot (T_f - T_i) \quad (5.3)$$

To express the heat capacity *C* as a function of specific heat *c*:

$$C = c \cdot m \rightarrow Q = c \cdot m \cdot \Delta T$$

or similarly:

$$Q = c \cdot m \cdot (T_f - T_i) \quad (5.4)$$

WATCH OUT!

The equation

$$Q = c \cdot m \cdot (T_f - T_i)$$

can be used for solids, liquids and gases, but never for a phase change phenomenon. This is because temperature remains constant throughout the transition.

COMPREHENSION QUESTIONS 3

Answer the following questions.

1 You place an object in contact with a hotter one. Can you tell whether or not the first object's temperature will increase? Why, or why not?
2 What does the amount of heat required to vary the temperature of a sample depend on?
3 What's the fundamental difference between heat capacity and specific heat?
4 Why are calories sometimes still used in calculations involving heat?
5 After providing the same amount of heat to two identical blocks of gold and aluminium, you put them in contact. In which direction is heat exchanged between the two blocks?

PRACTICE

3 Fill in the gaps with the appropriate words.

surroundings	system	universe	closed
mass	isolated	heat	else
set	open	environment	mentioned

In texts about [1] .... and thermodynamics, the words '[2] .... ' and 'interaction' are often [3] .... The definition of 'system' is "any object or [4] .... of objects under study". Everything [5] .... in the universe is referred to as the system's [6] .... , its *surroundings*, or the [7] .... A [8] .... system is one in which no mass can enter or leave, but which still allows energy exchange with its [9] .... In an [10] .... system, by contrast, both [11] .... and energy can enter or leave. An [12] .... system exchanges neither mass nor energy with its environment.

4 The bold words below are in the wrong sentences, so the sentences don't make sense at all! Using what you have learnt in this unit, put the bold words in the right sentences.

1 Internal energy is the energy of a system that is **required** with its microscopic components.
2 Internal energy is thermal energy plus **is** energy.
3 Heat **bond** energy in transfer between a system and its surroundings.
4 Heat always **capacity** spontaneously from a body at a higher temperature to a body at a lower temperature.
5 The amount of energy **associated** to raise the temperature of a particular sample of a substance by 1 °C is called the substance's heat capacity.
6 Specific heat is heat **flows** per unit mass and therefore its units.

5 **There are four ways (a-d) to complete the sentences below. Which is correct? Explain why, and use the texts in this unit to help you.**

1 **Heat spontaneously flows...**
  a from a bigger body to a smaller body.
  b between two bodies in thermal contact.
  c between two bodies in thermal equilibrium.
  d from a body at higher temperature to a body at lower temperature.

2 **Heat capacity...**
  a doubles when you double the quantity of a substance.
  b halves if the mass of the object doubles.
  c is constant for any given object.
  d is inversely proportional to the object's mass.

3 **Specific heat...**
  a doubles when you double the quantity of a substance.
  b halves if the mass of a substance doubles.
  c is constant for a given object.
  d is inversely proportional to an object's mass.

↑ The calorimeter, a device used to measure heat capacity.

Applied Physics

6 **What is an object (mass =1 kg) made of if you need to provide 36,000 J in order to increase its temperature from 20 °C to 100 °C?**

Known

$Q = 36{,}000$ J

$m = 1$ kg

$T_i = 20$ °C

$T_f = 100$ °C

Find

What is the object made of?

Analysis

In order to understand what the object is made of, you need to calculate its specific heat.

To solve the equation 5.4 for specific heat c: $Q = c \cdot m \cdot (T_f - T_i)$

$$c = \frac{Q}{m \cdot (T_f - T_i)} = \frac{36{,}000}{1 \cdot (100 - 20)} = 450 \frac{\text{j}}{\text{kg K}}$$

The specific heat table above indicates that the object is made of iron.

7 **A 100 g sample of iron is at a temperature of 20 °C. If 1,500 J of energy are added to it by heating, what will its final temperature be?**

8 **A car's cooling system holds 16 L of water. If the water temperature rises from 10 °C to 90 °C, how much heat has the water absorbed?**

PRODUCTION

9 Listening Activity 🎧 20

1 **With your partner, read the text and complete the gaps with the words below. When you have finished, listen and check.**

2 **Draw the two phases of the experiment in the boxes below, making sure to label everything.**

3 **Explain why this happens.**

Tyndall's experiment

1 **Consider Tyndall's experiment:**

temperature lead thermal iron boiling

Step 1: Four identical balls made of aluminium, 1 ...., brass and 2 .... are placed in a container of 3 .... water. After a certain time they will reach 4 .... equilibrium with the boiling water, and therefore will have the same 5 .... as the water (100 °C).

aluminium slab iron paraffin brass

Step 2: Then, the four balls are placed on a slab of scale wax. The 6 .... ball almost immediately melts the paraffin and falls through it. Shortly afterwards the 7 .... ball melts through the wax, while the 8 .... ball does not melt enough wax to fall through. The lead ball barely melts the 9 .... and remains on the 10 ....

2

Step 1	Step 2

3 ....

....

....

....

10 Working in groups, discuss the following questions and then write down your answer. When you have finished, compare your answers with the other groups.

1 A physicist adds 10 J of energy to the same amount of water, gold, and mercury at the same temperature and pressure. Can you rank the samples in order of increasing temperature after the energy has been added to each sample?

2 Consider three blocks of ice, gold, and mercury with an identical mass. How are the samples ranked in order of energy needed to increase the temperature of each by 20 °C?

3 The Lying Game: get into a group of four people, and take it in turns to read out statements. They can be true statements like "a body cannot possess heat", or false statements like "a body that possesses heat will lose heat to its surroundings if they are cooler". Your group has to guess whether your statements are true or false, and each person gets a point for a correct answer. The student with the highest number of points wins!

11 Get into a group of three, and use the school library and the Internet to find answers to the following questions.

1 Why do cities have a higher average night-time temperature than the surrounding countryside? Use what you have learnt in this unit to help you.

2 Why is water used in domestic heating systems?

Share your research tasks, and collaboratively write a three-page report on your findings.

UNIT

6

Heat Transfer

LEAD-IN

1 **Working in groups of three or four, state whether the following sentences are *true* or *false*, and correct the false ones.**

1 An object can feel warmer or colder than another object at the same temperature. T F

2 The air in one part of a room may be lighter or heavier than the air in another part of the room. T F

3 There wouldn't be any life on Earth without radiation. T F

2 **Match the terms (1-7) to their corresponding definitions (a-g).**

☐ 1 Blackbody

☐ 2 Emissivity

☐ 3 Grey surface

☐ 4 Bounding surface

☐ 5 Bulk motion

☐ 6 Heat transfer coefficient

☐ 7 Buoyancy forces

a The amount of heat that passes through a unit area of a medium or a system in a unit time, when the temperature difference between the boundaries of the system is 1 °C.

b The way that a large number of molecules move collectively or as aggregates.

c A surface that meets the edge of a fluid in motion.

d The upward force a fluid exerts on a body totally or partially immersed in it.

e The ratio of the radiation emitted by a surface to the radiation emitted by a perfect blackbody radiator at the same temperature.

f Absorbs all incident radiation and reflects none.

g Characterised by a surface emissivity independent of wavelength, so that no particular wavelength (or colour) is favoured.

READING AND LISTENING

LISTENING ACTIVITY

Working with a partner, read the text and circle the correct word in the pairs. Then, listen to the text and check your answers.

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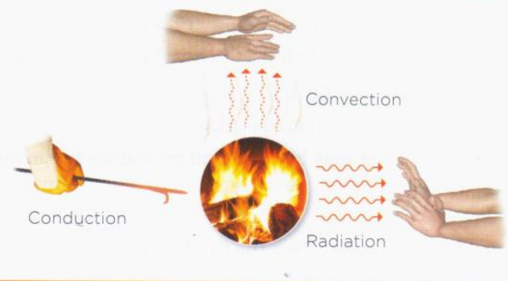
An Introduction to Heat Transfer

Examples of heat transfer phenomena are everywhere you are! **Conduction heat transfer** will be well-known 1 to / for you: you will have experienced it if you have ever burnt yourself 2 on / in a hot pan by touching it, or if you have experienced different sensations when touching plastic handles and metal ones.

If you can feel warm air 3 away / around you from the heater in your room, and you are not touching the heater, you are experiencing **convection heat transfer**. A current of warm air in contact 4 to / with the hot heater will rise 5 upward / downward in a bulk motion as cold air falls and replaces it. The main source of energy 6 in / for life on Earth is the Sun. Electromagnetic waves cover the long distance 7 from / in the Sun and heat the Earth in a process called **radiation heat transfer**.

We refer to different 8 types / effects of heat transfer processes as **modes**. When there is a temperature variation within a solid or fluid medium, we use the term **conduction** to refer to the heat transfer that occurs across it.

By contrast, the term **convection** refers to heat transfer that occurs between a surface and a moving fluid when the two are at different temperatures. The third mode of heat transfer is thermal **radiation**: all surfaces of finite temperature (i.e. different from zero kelvin) emit energy [9] in the form of / between electromagnetic waves. Hence, in the absence of an intervening medium, net heat transfer by radiation will occur [10] between / among two surfaces at different temperatures.



Conduction Heat Transfer

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Conduction may be seen as the transfer of energy from the more energetic particles of a substance to its less energetic particles, and is *caused by interactions between the particles.*

In gaseous or liquid media, constant collisions between molecules cause a transfer of energy from more energetic molecules (i.e. molecules at a higher temperature) to less energetic molecules (i.e. molecules at a lower temperature).

What happens in a solid is quite similar. If a metal spoon is placed in a cup of hot coffee, the end above the coffee's surface will warm up. Molecules in the spoon that are in contact with the coffee will experience an increase in vibrational energy, and approach thermal equilibrium with it. Energy will then be conducted along the spoon for the same reason.

Conduction energy transfer happens through lattice waves induced by atomic vibrations. In a non-conductor, energy transfer happens exclusively via these lattice waves, while in a conductor it is also due to the translational motion of free electrons in metallic bonds. These electrons are also responsible for electrical conduction.

The amount of energy transferred via heat conduction per unit time is calculated by **Fourier's Law**. For a plane wall in steady state conditions, the temperature distribution is linear and the rate equation is:

$$Q = k\frac{\Delta T \cdot A}{d} \cdot \Delta t \quad (6.1)$$

where k indicates the proportionality constant, a property of heat transfer known as *thermal conductivity* [W/(m·K)], which is a characteristic of the wall's material.

ΔT is the temperature difference between the internal and external faces of the wall, A is the area of the plane wall, d is the wall thickness, and Δt is the time interval.

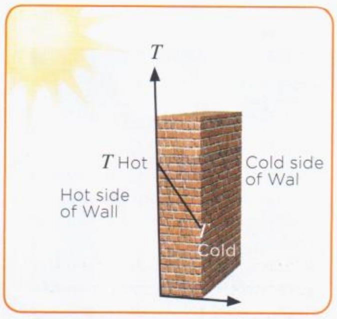
COMPREHENSION QUESTIONS 1

Answer the following questions.

1 What are the different modes of heat transfer?
2 Which modes of heat transfer can happen across a vacuum?
3 In all three cases, why does heat transfer occur?

Thermal conductivity of common substances

Substance	Thermal conductivity [W/(m k)]
Metals (at 25 °C)	
Aluminium	238
Copper	397
Gold	314
Iron	79.5
Lead	34.7
Silver	427
Non metals	
Concrete	0.8
Asbestos	0.08
Glass	0.8
Ice	2
Water	0.6
Wood	0.08
Gases (at 20 °C)	
Air	0.023
Helium	0.138
Hydrogen	0.172



COMPREHENSION QUESTIONS 2

Answer the following questions.

1 What does the 'temperature' of a medium measure?
2 When they collide, in which direction along the energy gradient do molecules transfer energy?
3 Which physical quantity is proportional or inversely proportional to heat transferred by conduction?

23 Convection Heat Transfer

LISTENING ACTIVITY

With your partner, consider the gaps in the text to the right. Try to put the right word in each gap. When you have finished, listen to the text to check your answers. Were they correct?

boards	molecules	vertical
difference	components	caused
lighter	contact	
atmospheric	external	

Convection heat transfer occurs when there is a [1] .... in temperature between a fluid in motion and a bounding surface. This fluid motion consists of a large number of [2] .... moving collectively or as aggregates (i.e. in bulk motion).
Convection heat transfer may be classified according to the nature of the fluid flow.

Forced convection happens when the fluid flow is caused by [3] .... means, such as a fan, a pump, or [4] .... winds. For example, a fan can be used to provide forced convection air-cooling for hot electrical [5] .... on a stack of circuit [6] .... in a computer.

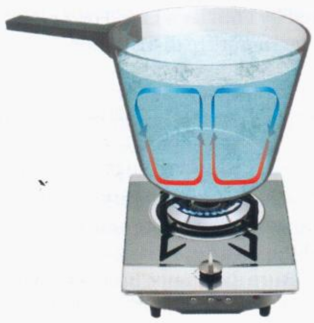
Free (or natural) convection happens when the fluid flow is induced by buoyancy forces, which arise from density differences [7] .... by temperature variations in the fluid.
An example of free convection is the heat transfer that occurs at home in radiators, during the winter. Air that comes into [8] .... with the hot components of a radiator experiences an increase in temperature, and hence a reduction in density.
As a consequence this air is [9] .... than the surrounding air, and buoyancy forces induce a [10] .... motion that replaces the ascending warm air with an inflow of cooler air.

COMPREHENSION QUESTIONS 3

Answer the following questions.

1 Under what circumstances does convection heat transfer occur?
2 Why are "a temperature difference" and "bulk motion" important to convection heat transfer?
3 What causes fluid motion in forced convection?
4 What induces convective fluid flow in free convection?
5 In examples of convection, what causes the decrease in the density of the fluid?

↓ Examples of free convection: heating a room with a hot radiator; convective motion of water in a pan heated from below.



Radiation Heat Transfer

Thermal radiation is energy emitted by matter at a finite temperature (i.e. a temperature different from zero kelvin). Although radiation is mainly associated with solid surfaces, emission may also occur from liquids and gases. Regardless of whether we are speaking about a gas, a liquid, or a solid, emission happens as a result of changes in the electron configurations in the material's constituent atoms or molecules, and the energy of the radiation is transported by electromagnetic waves. **While the transfer of energy by conduction or convection requires the presence of a material medium, radiation transfer occurs most efficiently in a vacuum.**
The rate at which an object radiates energy is proportional to the fourth power of its absolute temperature. This is known as the **Stefan–Boltzmann law**, and is expressed in the following equation:

□ $P = \sigma \cdot \varepsilon \cdot A \cdot T_S^4$ (6.2a) □ $P = \sigma \cdot \varepsilon \cdot A \cdot T_S^2$ (6.2b)

P is the maximum power in watts radiated from the surface of the object, T_S is the *absolute* temperature (K) of the surface, σ is the *Stefan–Boltzmann constant* ($\sigma = 5.67 \cdot 10^{-8}$ W/m$^2 \cdot$ K^4), and ε is a radiative property of the surface called *emissivity*. The value of emissivity is in the range $0 \leq \varepsilon \leq 1$, and it indicates how efficiently the surface emits compared to an ideal radiator or *blackbody*.
Moreover, if radiation is incident upon a surface, a portion of it will be absorbed, and the rate at which energy is absorbed per unit surface area can be calculated if you know the surface radiative property termed *absorptivity (α)*. That is:

□ $P_{abs} = \varepsilon \cdot P_{inc}$ (6.3a) □ $P_{abs} = \alpha \cdot P_{inc}$ (6.3b)

$0 \leq \alpha \leq 1$, P_{abs} is the thermal power absorbed, and P_{inc} is the incident thermal power. The emission of radiation reduces the thermal energy of the body, whereas absorption increases it.
Assuming the surface to be a grey surface (α = ε), the net exchange per unit area between a small surface and a much larger surface that completely surrounds it is:

□ $P_{net} = \sigma \cdot \varepsilon \cdot A \cdot \left(T_S^4 - T_{sur}^4\right)$ (6.4a)

□ $P_{net} = \sigma \cdot \alpha \cdot A \cdot \left(T_{sur}^4 - T_S^4\right)$ (6.4b)

In this expression, P_{net} is the net thermal power, *A* is the surface area, ε is its emissivity, T_S is the temperature of the surface, and T_{sur} is the temperature of the surroundings. In this special case, the area and emissivity of the surroundings do not influence the net heat exchange rate.
The surface within the surroundings may also simultaneously transfer heat by convection to the surrounding gas. The total rate of heat transfer within the surface is, then, the sum of the heat rates from the two modes.

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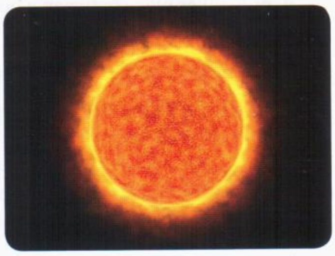
LISTENING ACTIVITY
Read and listen the text. When you come to a formula, listen carefully and tick the one you hear.



COMPREHENSION QUESTIONS 4
Answer the following questions.

1. Does radiation heat transfer occur in liquids and gases?
2. Does a real surface emit more or less than an ideal one?
3. Does emission of radiation increase or decrease the energy of a body?
4. Can radiation heat transfer occur alongside convection and conduction heat transfer?

PRACTICE

3 Fill in the gaps with the appropriate words or expressions.

surface different place fluid

1 Convection heat transfer takes [1] .... between a [2] .... and a [3] .... that are at [4] .... temperatures.

finite body temperature occur

2 Radiation heat transfer will [5] .... if a [6] .... has a [7] .... [8] ....

that medium temperature difference two points heat transfer

3 When a [9] .... exists between [10] .... of a medium, conduction [11] .... will occur across [12] ....

4 The bold words below are in the wrong sentences, so the sentences don't make sense at all! Using the texts in this unit to help you, put the bold words in the right sentences.

1 A current of warm **liquids** in contact with a hot **surface** will **presence** upward.
2 The term '**conduction**' refers to the heat transfer that occurs between a **medium** and a moving fluid at **air** temperatures.
3 **Convection** heat transfer happens in solids, **vacuum** and **heater**.
4 **Energy**, convection, and conduction heat transfer are not **different**: they often occur **mutually exclusive**.
5 Heat transfer of **radiation** by conduction or convection requires the **rise** of a material **gases**, while radiation transfer also occurs in a **simultaneously**.

5 There are four ways (a-d) to complete the sentence below. Which is correct? Explain why, and use the texts in this unit to help you.

1 **Conduction heat transfer...**
  a always occurs in the presence of a temperature difference.
  b happens most efficiently via the motion and interactions of free electrons in metallic bonds.
  c only occurs between two separate objects at different temperatures.
  d only takes place between a body at a higher temperature and a body at a lower temperature.

2 **Convection heat transfer...**
  a occurs between a fluid and a surface at different temperatures.
  b always takes place in the presence of a temperature difference.
  c only happens in gases.
  d is the only mode of heat transfer that can occur when there is a temperature difference between two points in a liquid.

3 **Radiation heat transfer...**
  a only occurs in a vacuum.
  b occurs only in solids when the surroundings are at a different temperature.
  c takes place only in solids.
  d is always occurring, because every medium has a temperature above zero kelvin.

4 **Heat transfer modes...**
  a take place only in specific media.
  b always take place together.
  c are different processes through which heat can be transferred.
  d are different processes that only depend on the medium through which heat transfer occurs.

Applied Physics

6 **A box with a total surface area of 1.50 m² and a side thickness of 2.0 cm is made of an insulating material. There is a 10.0 W electric heater inside the box, and it maintains the box's internal temperature at 20.0 °C above its external temperature. Find the thermal conductivity *k* of the insulating material.**

Known

$A = 1.50\ \text{m}^2$
$d = 2.0\ \text{cm} = 0.02\ \text{m}$ (wall thickness)
$P = 10\ \text{W}$ (heater power)
$\Delta T = 20\ °\text{C}$

Find

$k = ?$

Analysis

Start from equation 6.1:

$$Q = k\frac{\Delta T \cdot A}{d} \cdot \Delta t$$

and divide both sides of the equation by the time interval Δt.
The ratio between Q and Δt is equal to the power P (in watts) provided by the electric heater inside the box:

$$P = \frac{Q}{\Delta t} = k\frac{\Delta T \cdot A}{d}$$

Solve the above equation for k:

$$k = \frac{P}{\frac{\Delta T \cdot A}{d}} = \frac{P \cdot d}{\Delta T \cdot A} = \frac{10 \cdot 0.02}{20 \cdot 1.5} = 0.007\ \frac{\text{W}}{\text{m}^2 \cdot °\text{C}}$$

7 **The surface of the Sun has a temperature of about 5,800 K, and its radius is $6.96 \cdot 10^8$ m. Calculate the energy radiated by the Sun every second. Assume that the emissivity of the Sun is 0.965.**

PRODUCTION

8 **Working in groups, discuss the following questions and then write down your answer. When you have finished, compare your answers with the other groups.**

1. You feel comfortable outside when the air temperature is 22 °C, but in a pool with a temperature of 22 °C, you feel cold. Why?
2. Is the atmospheric wind that cools a building's surface an example of natural convection?
3. When you get out of the shower and put one foot on a rug and the other on a ceramic tile, do you feel different sensations? If so, how can you explain it?
4. A Dewar flask (also known as a Thermos flask) is a vessel that keeps your drink icy cold or steaming hot in any weather conditions.
   It is a double-walled vessel with an airless space inside, and its inner wall is silvered.
   Explain why its construction makes it such a good insulator.

9 **Get into a group of three, and use the school library and the Internet to find answers to the following questions.**

1. The greenhouse effect is a geophysical phenomenon that has an important role in the temperature equilibrium of our planet. Without temperature equilibrium, life wouldn't be the same. Why not?
2. Think of ways in which your home and the objects inside it are designed to control heat loss. Which materials could you use to minimise domestic heat loss or maximise domestic heat transfer? For every example, make a note of what the material is, what it does, and how it works.
   Share your research tasks, and collaboratively write a three-page report on your findings.

10 **Ceiling fans are sometimes reversible, so that they can blow air upwards or downwards. How do they operate in summer, and how do they operate in winter? Together, write a short and concise answer.**

Test your Competences

DISCUSSION

1 There are many everyday applications of your studies of heat, thermal equilibrium, heat capacity, specific heat, and modes of heat transfer. Thinking about what you learnt in units 4, 5 and 6, discuss the situations described below with your partner and write a short explanation.

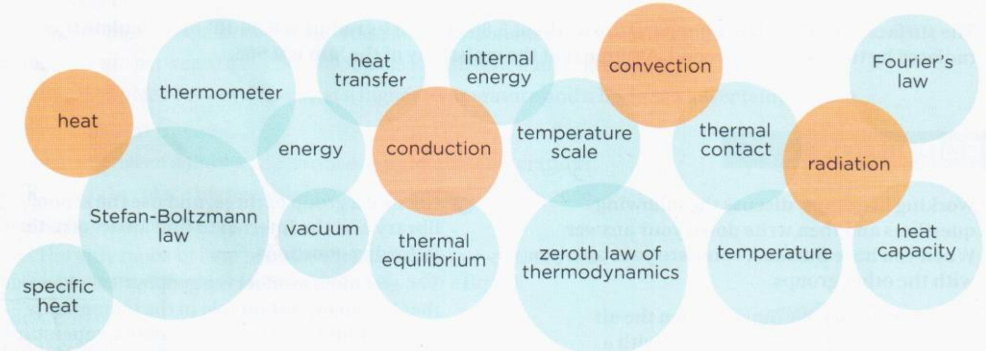
1. The weather in coastal areas is profoundly influenced by the high specific heat of water. Can you explain why?
2. Why do heavy curtains over the windows help keep a home cool in the summer and warm in the winter?
3. CPU microprocessor chips have "heat sinks" glued to them, and these heat sink fans have a lot of blades. Why is that?
4. You are at a camp site, cooking a piece of meat over an open fire. Your friend, who camps more often than you, tells you not to use a high flame. Can you explain why? (Note that carbon is a good thermal insulator.)
5. An emergency kit for hiking always contains a sheet of thin shiny plastic foil, coated with a metal. How can such a light blanket help keep you warm?

MIND MAP

2 With your partner, consider the ideas in the following diagram. What are they, and what is their significance to the subject of heat? If you're not sure, look back through your notes.

• Working with your partner, draw a mind map using the words from the circles and any others you think are necessary. It may be a good idea to start with the orange circles.

• Draw links between the ideas on your map to show how they are logically connected, and explain them to another pair of students. Make brief notes next to the links.



RESEARCH

3 Form groups of three, and use the school library and the Internet to elaborate on the meaning of this sentence from a scientific paper:

"Waste heat from industrial processes sometimes causes thermal pollution."

Think about:

• what waste heat and thermal pollution are;

• how they are produced;

• which industrial processes produce most;

• whether it is a problem, and why.

Remember to divide your tasks with the rest of your group, and then share your research. Together, write one report.