Physics

2017

Unit 1 - Area of Study 1

Thermodynamics

Name:________________________

Thermodynamics

A brief history

Over 2000 years ago Greek philosophers speculated that matter consisted of "elemental-atoms" in rapid motion. The result of this motion was heat. In the 1750s it was suggested that heat was a fluid – caloric – that flows from hot to cold objects. A hot object was said to contain more caloric than a cold object. An object expanded when heated due to the caloric filling the spaces between the "atoms" and pushed them apart. The amount of caloric was unchanged when a hot and cold object were bought together – only the distribution changed.

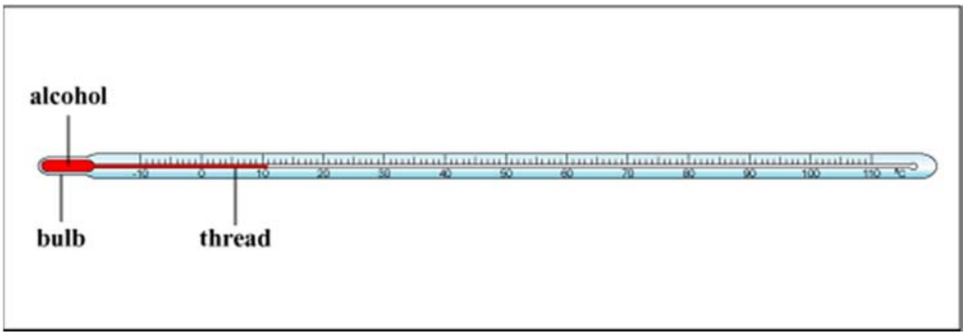
Newton believed that heat was due to "atomic" motions. Bernoulli assumed that moving particles would produce pressure by hitting the walls of a container, heating would cause the particles to move faster and hence increase pressure. It was discovered early on that work could be done to produce heat (generally in the form of friction), but it wasn't until the 18th century that it was demonstrated that heat transfer could be used to perform work. Thus showing that heat is a form of energy. This allowed for the development of things like the steam engine.

Temperature

Temperature is a measure of how "hot" something is. The human sense of touch is capable of determining if one thing is hotter than another, but can't tell us how hot something is. We need to quantify temperature.

Thermometers

Thermometers are used to measure temperature. The typical thermometer uses the expansion of a liquid (often mercury or alcohol) to measure the temperature. These are made of glass and have a bulb at one end containing the dyed alcohol. When the temperature rises the alcohol expands (reasonably linearly) and moves along the thread. Alcohol doesn't turn solid until -115 ºC, so can be used to measure temperatures below 0 ºC.



Other thermometers use variations in the electrical resistance of wires, the pressure or volume of a gas, or the colour of certain chemicals to measure temperature.

Temperature Scales

There are a range of temperature scales commonly used. In Physics we use either the **Celsius** scale (this used to be called the Centigrade scale), or the **Kelvin** scale.

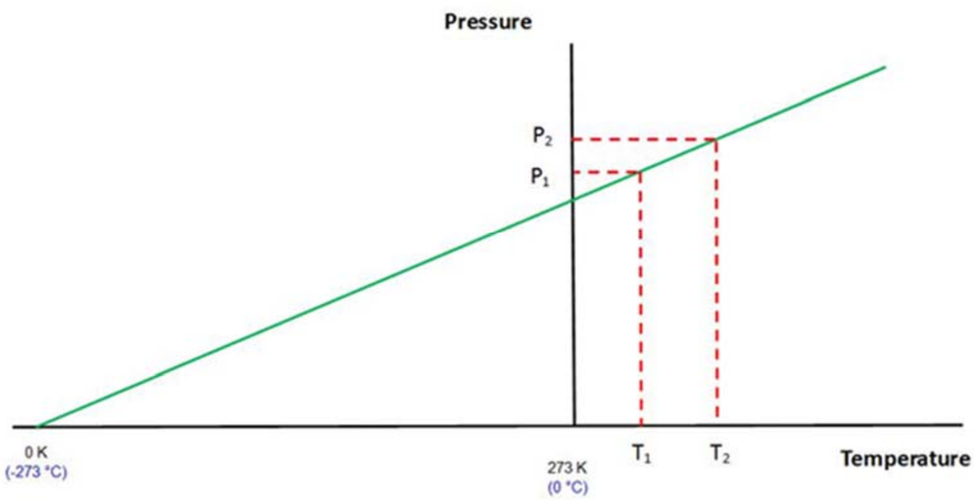
Celsius is defined by a freezing point of water at 0 ºC and boiling point of water at 100 ºC. The lower fixed point (or ice point) is the temperature at which pure ice melts at normal atmospheric pressure. The upper fixed point (or steam point) is the temperature at which pure water boils under normal atmospheric pressure.

In 1848, Lord Kelvin proposed an **absolute temperature scale** with zero set at -273 ºC. The Kelvin scale uses units of kelvin (K), and has the same divisions as the Celsius scale. This is the scale we use most commonly in physics.

Absolute Zero

Absolute zero is the lowest possible temperature where nothing could be colder and no thermal energy (heat) remains in a substance. Absolute zero is the point at which the fundamental particles of nature have minimal vibrational motion, retaining only quantum mechanical, so-called “zero-point energy” induced particle motion. All molecular motion does not cease at absolute zero, but no energy from molecular motion (i.e, heat energy) is available for transfer to other systems. Therefore, the energy at absolute zero is minimal.

The idea that there was a lowest temperature comes from the contraction of gases at low pressures. The pressure of an ideal gas, at constant volume, decreases linearly with temperature. A real gas condenses to a liquid or a solid at a temperature higher than absolute zero; therefore, the ideal gas law is only an approximation to real gas behaviour. However, if the graph is extrapolated, it intersects at -273.15 ºC, as can be seen below.



Absolute zero is defined as precisely 0 K on the Kelvin scale and -273.15 ºC on the Celsius scale. This temperature cannot be reached; it can only be approached. Scientists have reached temperatures within nano-degrees of 0 K.

Absolute temperature in kelvin = temperature in ºC + 273

There is no upper limit on temperature, except the limit of the amount of energy in the Universe.

Question 18

What are the two fixed points the Celsius scale? How are these points determined?

Question 19

What are these upper and lower fixed points in kelvin?

Question 20

Convert a room temperature of 22 ºC to kelvin.

Question 21

Convert 400 ºC to kelvin

Question 22

Convert -27 ºC to kelvin

Question 23

Convert 50 K to ºC

Question 24

Convert 1 000 K to ºC

Question 25

Convert the boiling point of alcohol, 79 °C to kelvin.

Question 26

A body is cooled from 80 °C to 23 °C. What is this temperature difference in kelvin?

Question 27

A gas is heated from 280 K to 350 K. What is this temperature interval in degrees Celsius?

Question 28

Order the following from coolest to warmest: the boiling point of water; 300 K, 0 °C, 30 °C, 200 K, -100 °C

Question 29

Of the following, which temperature does not exist?

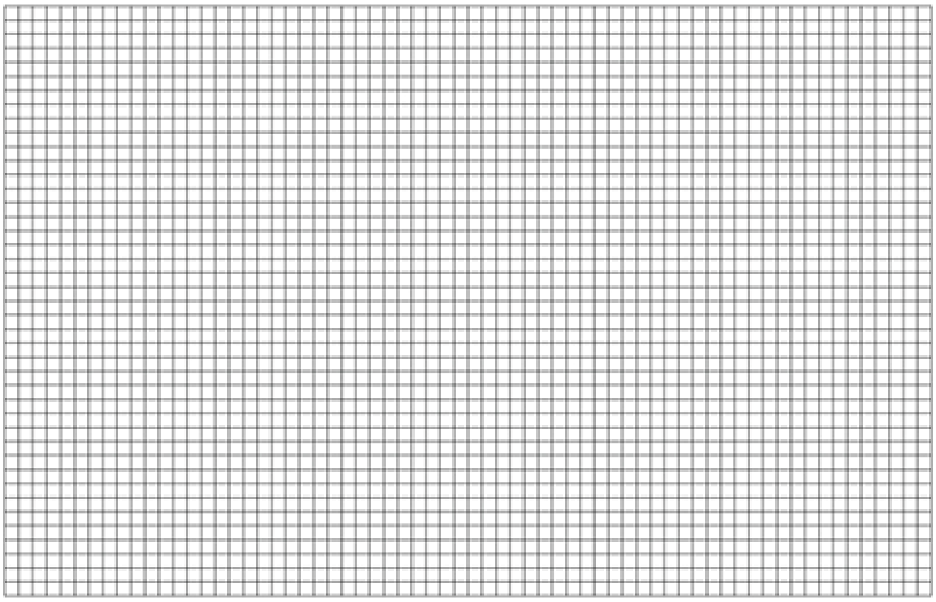
A 100 °C **B** -80 K **C** -80 °C **D** 100 000 K

Question 30

What physical properties of materials make them suitable for use in a thermometer?

Question 31

The resistance of platinum wires varies linearly with temperature. In a certain resistance thermometer, the resistance of a platinum coil at the lower and upper fixed points are 2.50 Ω and 3.30 Ω respectively. Plot the graph of resistance versus temperature.



Estimate the temperature corresponding to a resistance of (i) 3.00 Ω and (ii) 2.70 Ω.

Question 32

What defines absolute zero?

Do questions

- **1-11** from chapter one of the textbook.

The Zeroth Law of Thermodynamics

The Zeroth Law of Thermodynamics is where **two bodies in contact with each other come to thermal equilibrium**. If two bodies A and B are separately in thermal equilibrium with a third body, C, then A and B are also in thermal equilibrium with each other.

The zeroth law of Thermodynamics, which is fundamental to all thermodynamics, is so named as it has priority over the first and second laws, and because it was recognised as a law after the first and second laws had been assigned their numbers.

Thermal energy

Heat is a form of energy, just like kinetic energy, potential energy, electrical energy, chemical energy, light energy, etc. The SI unit for energy is the **joule (J)** after James Prescott Joule. One joule of thermal energy is the heat required to raise the temperature of 1 g of dry air by 1 K or 1 g of water by 0.24 K.

The model we use to understand heating as an energy transfer is the kinetic particle model. Kinetic energy is the energy a body possesses due to its motion. The kinetic theory of matter states that matter is made up of extremely tiny particles (ions, atoms or molecules) which can move at different speeds because of the kinetic energy they possess. The way these particles are arranged determines whether the substance is a solid, liquid or gas. These particles are in continuous motion, their motion, and hence state can be changed by adding or removing energy (in the form of heat).

The higher the temperature, the faster the particles are moving (or vibrating) hence the greater the kinetic energy. This kinetic energy is associated with the random, incoherent movements (or vibrations) of the particles. This is different from the kinetic energy associated with the collective movement of the particles, which occurs when the whole container or object moves.

The internal energy of a body is the sum of the potential and the kinetic energy of all its particles. It is measured in joules. The energy of the particles may be associated with their rotational motion. Internal energy may also be in the arrangement of the particles, heating may increase the internal energy by causing a rearrangement of the particles to give a change of phase (e.g. from a solid to a liquid). It is only the increase in the kinetic energy (or vibrational energy) of the particles which cause a change in temperature.

The definition of the Kelvin scale is that absolute zero is when the particles have zero thermal movement.

States of matter

There are four recognised main states of matter: **solid, liquid, gas** and **plasma**. Substances can change their states when physical conditions such as temperature or pressure alter.

Solids

In a solid the particles are held tightly together in a set array. The particles cannot move away from each other, but they can vibrate about a mean position. The speed at which the particles vibrate depends on the temperature of the solid. The higher the temperature the faster the particles vibrate and the more kinetic energy the particles will have.

Liquids

The particles are further apart than in a solid. They are in constant motion and are free to move about. Liquids do not have a definite shape and can flow. Forces of attraction cause the particles to occupy a definite volume.

Gases

The particles of a gas are almost completely free of each other's influence. They are free to move wherever they wish. They have no particular shape. The particles are moving much faster than those in a liquid or a solid. Elastic collisions occur between particles and the forces of attraction between particles are weak.

The average translational kinetic energy (KE) of a molecule of an ideal gas is directly proportional to the absolute temperature of the gas.

This can be summarised as: $KE_{ave} = \frac{1}{2}mv_{ave}^2 = \frac{3}{2}kT$

Where m is the mass in kg, v_{ave} is the average translational speed of the gas molecules, $k = 1.38 \times 10^{-23}$ J K^{-1} (the Boltzmann constant) and T is the temperature in kelvin.

If two gases, initially at different temperatures, are combined within a single container, molecules of the hotter gas will transfer energy through intermolecular collisions to the molecules of the cooler gas until thermal equilibrium is established at a single final temperature.

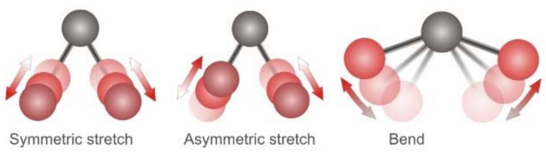
Heating

When you heat a substance, you add energy to it.

For a solid, the molecules and atoms vibrate faster. As atoms vibrate faster, the space between atoms increases. The motion and spacing of the particles determines the state of matter of the substance. The end result of increased molecular motion is that the object expands and takes up more space.

It is more complex for a gas. If the gas is monatomic, (eg Neon), the atoms move more when heat (energy) is added. If the gas is diatomic, (eg Oxygen, O_2) the molecules can also spin and stretch. If the gas is multi-atom, (eg Water H_2O), the molecules can move more, spin, stretch and twist.

Liquids exhibit features of both solids and gases.



Effects of pressure

Experiments show that increased pressure raises the boiling point, and decreasing pressure lowers the boiling point. For example, on Mount Everest water boils at 70 ºC. Pressure cookers are used in the kitchen to increase the boiling point, hence higher temperatures can be reached. This cuts down on the cooking time required. Changing the pressure can also affect the melting point of substances.

Other things, such as impurities can also alter melting and boiling points. Adding salt to water increases the boiling point a few degrees, but can lower the freezing point by up to 20 ºC. This is why salt is often added to icy roads to melt the ice.

The First Law of Thermodynamics

The change in internal energy of a system is equal to the sum of energy entering the system through heating and energy entering the system through work done on it.

The work done by Joule gave rise to the idea that energy is conserved, which is most often expressed as the 'law of conservation of energy'. Joule's work showed that the transfer of energy (E) to a system could give rise to an increase in internal energy (U) of a system by an exactly equivalent amount.

$$\therefore \Delta E = \Delta U$$

In Joule's studies, ΔE was measured as a quantity of work (W). The amount of energy transferred is called work. The body losing energy does work, the body gaining energy has work done on it. Work is a scalar quantity and the unit of Work is the joule (J). Whenever work is done, energy is transformed from one form to another.

$$\therefore \Delta W = \Delta U$$

Instead of doing work, an alternative way to increase the internal energy of a system is to heat it (that is, to transfer energy to it by means of a temperature gradient). The temperature of a system may be increased by allowing an amount of thermal energy (Q) to enter the system.

$$\therefore \Delta Q = \Delta U$$

Most changes do not happen *entirely* through transfer of energy by heating or *entirely* through the transfer of energy by work. This means that the change in internal energy (U) is a combination of work and heating;

$$\therefore \Delta U = \Delta Q + \Delta W$$

The equation is written as $\mathbf{\Delta U = \Delta Q + \Delta W}$, when ΔQ is the heat energy supplied to the system, and ΔW is the work done *on* the system, as the system is gaining energy.

The equation is written as $\mathbf{\Delta U = \Delta Q - \Delta W}$, when ΔQ is the heat energy supplied to the system, and ΔW is the work done *by* the system, as the system is losing energy.

It is important to pay attention to the difference between work done *on* a system and work done *by* a system.

Adiabatic

A change which involves no heat energy into or out of a system is called an **adiabatic** process. (e.g the rapid compression of a gas in a bike pump, with the outlet blocked.) As the plunger is depressed, the air inside is compressed. The mechanical work done in compressing the gas increases the internal energy of the air in the pump, and hence its temperature.

Isothermal

A change which involves no temperature change is called **isothermal.** (e.g. the very, very slow compression of a bike pump.)

The Second Law of Thermodynamics

The second law of thermodynamics asserts that natural processes run only in one direction, and are not reversible. An example of this is that heat always flows spontaneously from a hotter body to a colder body, never in reverse (unless external work is performed on the system.

No process is possible in which there is an overall decrease in the entropy of the Universe.

Entropy is a measure of the distribution of matter and energy in a system, a measure of the disorder or chaos in it. The larger the entropy the more disorder. Thermal equilibrium involves an increase in entropy, since the number of ways of arranging the particles (that is the disorder) increases.

Question 33

If the temperature of an object is lowered, what happens to the average kinetic energy of its particles?

Question 34

A 220 mL glass full of water is in thermal equilibrium with the table it rests on. Further along the table an alcohol thermometer reads 23 ºC and rests a test tube of hydrochloric acid. The hydrochloric acid is in thermal equilibrium with the table. What is the temperature of the water?

Question 35

What is the unit for energy?

Question 36

A pot of water is placed on the stove to heat up. What is happening to the water molecules while they heat up? (select only one answer)

A They are gaining translational kinetic energy

B They are gaining internal energy

C They are losing energy

D They are maintaining a constant level of energy, as energy cannot be created or destroyed.

Question 37

What freedom of movement do molecules in a solid have?

Question 38

What freedom of movement do molecules in a liquid have?

Question 39

What freedom of movement do molecules in a gas have?

Question 40

A deep sea diver is 30 m under water when she breathes out, creating a bubble. The bubble then rises to the surface. Given that water pressure increases with depth, what happens to the size of the bubble as it rises to the surface?

Question 41

Oxygen gas is in a spherical container of radius 0.1 m, the radius of the container is decreased to 0.05 m without the loss of any gas. What happens to the temperature of the gas as it is compressed?

Question 42

There are two ways to liquefy a gas, cooling it passed the condensation point or compressing it until it liquefies. A combination of both these strategies is usually used. Why do you think this might be the case?

Question 43

A hot brick does 40 kJ of work on the table it is sitting on. The brick also transfers 15 kJ of thermal energy into the air. What is the change in internal energy of the brick?

Question 44

A student does 100 J of work on a pot of cold water by stirring vigorously, the water also gains 30 J of thermal energy from its surroundings. What is the change in internal energy on the water?

Question 45

A scientist very carefully does mechanical work on a container of liquid sodium. The liquid loses 320 J of energy to the atmosphere, but gains 230 J of energy overall. How much work did the scientist do?

Question 46

Entropy is a measure of the distribution of matter and energy in a system, a measure of the disorder or chaos in it. The larger the entropy the more disorder. Can entropy ever decrease on the universal scale?

Do questions

- **12-17** from chapter one of the textbook

Heat capacity

The temperature of a body depends on its internal energy, to raise the temperature, energy needs to be transferred to the body. Experimentally it has been found that the thermal energy (Q) transferred is proportional to the increase in temperature ΔT.

$\therefore Q \propto \Delta T$

This can be written as $Q = C\,\Delta T$, where C is a constant called the heat capacity of the body. A larger body requires more heat to produce a given rise in temperature. Experimentally it has been found that $Q \propto m$ (for a given rise in temperature).

This gives **$Q = mc\,\Delta T$**, where c, is called the **specific heat capacity** of the material.

The specific heat capacity (c) is the energy transferred by heating required to increase the temperature of 1 kg of the substance by 1 K or ºC.

The specific heat capacity of a substance is a property of the substance and does not depend on the size, nor shape of the substance.

The specific heat capacity has units of J kg^{-1} K^{-1}.

Substance	**Specific heat capacity (J kg^{-1} K^{-1})**
Water	4 186
Air	1 000
Alcohol	2 500
Human body (average)	3 500
Aluminium	900
Copper	380
Iron	490
Glass	600
Ice	2 093
Mercury	140
Hydrogen	14 320
Helium	5 167

Water

Water has a high specific heat capacity. This is a very useful property.

- Water is used in the cooling systems of cars because it takes a lot of energy to raise the temperature of the water
- Seawater takes a much longer time than land to heat up and cool down. The small temperature change in water results in coastal areas being cooler in summer and milder in winter than inland areas.
- The human body contains a lot of water. This means that we respond slowly to changes in the external temperatures.

Conservation of Energy

When two bodies of different temperatures are placed in contact inside an insulated container, energy is transferred from the body at a higher temperature to that at a lower temperature. The energy transfer stops when they reach the same temperature. During the transfer process, **the energy lost by one body is equal to the energy gained by the other body.**

This agrees in principle with the **law of conservation of energy.** In reality, there will be some energy transferred to the outside environment.

Question 47

Calculate the heat (thermal energy) required to raise the temperature of 5 kg of brass from 10 ºC to 60 ºC. The specific heat capacity of brass is 377 J kg^{-1} K^{-1}

Question 48

Equal amounts of heat are absorbed by 100 g samples of various solid metals with differing specific heat values. Which of the following statements is true regarding metals and their specific heat values?

A The metal with the smallest specific heat will undergo the smallest change in temperature.

B The metal with the greatest specific heat will undergo the greatest change in temperature

C The metal with the greatest specific heat will undergo the smallest change in temperature.

Question 49

131 040 J of energy is transferred to 4 kg of water (c = 4 200 J kg^{-1} K^{-1}), with an initial temperature of 10 ºC. What is the final temperature of the water?

Question 50

A lump of metal was transferred to 1 kg of water and the temperature of the water increased from 20 ºC to 54 ºC. Find

(i) the energy lost be the metal

(ii) the energy gained by the water.

Question 51

A 1.5 kg sample is placed in an oven and heated 5 °C. The energy used to do this was 4560 J. What is the specific heat capacity of this material? Referring to your notes, what material might this sample be?

Question 52

How much energy is needed to warm 5.0 kg of blood in a child's body from 34 °C to 37 °C? (Assume that blood has the same specific heat capacity as water).

Question 53

How many joules of energy are lost when 865 g of aluminium cools from 120 °C to 55 °C? (specific heat capacity = 8.80×10^2 J kg^{-1} K^{-1}).

Question 54

In an experiment, 1.1 kg of aluminium is heated to 92 ºC. It is then dropped into 0.5 kg of water at 12 ºC.
Find the final temperature of the mixture. (c_{water} = 4 200 J kg^{-1} K^{-1}, $c_{aluminium}$ = 880 J kg^{-1} K^{-1}).

Question 55

Find the final temperature when 60 kg of iron pellets at 120 ºC are dropped into 200 kg of water at 20 ºC. (c_w = 4 200 J kg^{-1} ºK, c_i = 440 J kg^{-1} K^{-1}.

Question 56

If 0.20 kg of water at 90 °C is mixed with 0.50 kg of water at 16 °C, what is the final temperature of the mixture?

Question 57

If 100 g of water at 95 °C is poured into a 500 g glass cup (with an initial temperature of 25 °C), what is the final temperature of the water and the cup? (specific heat capacity of glass = 8.42 x 10^2 J kg^{-1} K^{-1}).

Do questions

- **18-21** from chapter one of the text book

Latent Heat

Melting point

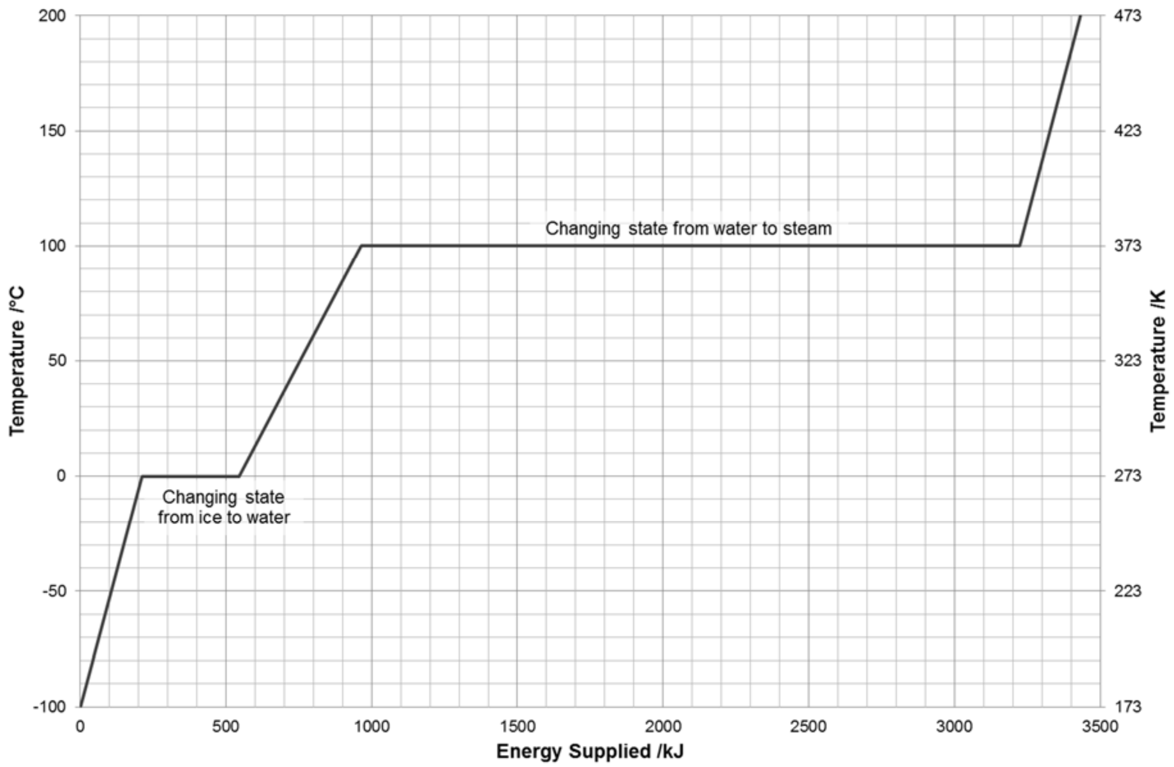
When a solid is heated its temperature remains constant as it changes into a liquid. This is called the melting point. The freezing point and melting point are the same for each substance. The term melting point is used to describe a solid into a liquid and the term freezing point is used to describe a liquid into a solid.

Boiling point

When bubbles of vapour are formed throughout a liquid the liquid is said to be boiling. Boiling is a change of state from liquid to gas (vapour).

Evaporation and Boiling

Evaporation and boiling are both a change of state from liquid to vapour (gas). Evaporation is a surface phenomenon and takes place at all temperatures. Boiling takes place throughout a liquid at a fixed temperature.



The energy required to change 1 kg of a substance from solid to liquid state without a change in temperature is called the **specific latent heat of fusion (l_f).** (the subscript is ‘f’ for fusion)

The energy required to change 1 kg of a substance from liquid to gaseous state without a change in temperature is called the **specific latent heat of vaporisation (l_v).**
The SI unit for specific heat is J kg^{-1}.

Q = *ml* where Q the energy (J), *m* is the mass (kg) and *l* the specific latent heat (J kg^{-1})

How does sweating cool humans?

Molecules with enough energy can escape from water (sweat) on the surface of the skin. As the most energetic molecules escape from the water, the less energetic ones are left behind. This means that the internal energy of the water is then lower, so its temperature is lower.

Alternatively, energy is required for water (sweat) on the surface of skin to evaporate. The energy needed for the water to evaporate comes from the rest of the water. This means that as the water evaporates it cools.

This is how evaporative cooling systems work to cool buildings. Scientists can also use this same process to lower the temperature of atoms down to the order of nano-kelvins (10^{-9} K).

For questions 58 - 65 use the following information about water $l_v = 2.3 \times 10^6$ J kg^{-1}, $l_f = 3.35 \times 10^5$ J kg^{-1}, $c_w = 4\,200$ J kg^{-1} K^{-1}, $c_{ice} = c_{steam} = 2\,100$ J kg^{-1} K^{-1}

Question 58

How much energy (in the form of heat) is required to melt 4 kg of ice at its melting point?

Question 59

Calculate the energy (in the form of heat) required to boil completely to a gas 0.2 kg of water at 100 ºC.

Question 60

Calculate the energy (in the form of heat) required to convert 4.0 kg of water at 10 ºC to steam at 100 ºC.

Question 61

What is the energy (in the form of heat) required to raise the temperature of 1 kg of water from 0 ºC to 100 ºC, and the energy required to change 1 kg of water at 100 ºC to steam? Therefore, what energy is required to turn 1 kg of water, initially at 0 ºC, into steam?

Question 62

Calculate the energy required to convert 0.4 kg of ice at 0 ºC to steam at 100 ºC.

Question 63

How much energy is required to melt 5.5 kg of ice at 0 ºC?

Question 64

How much energy is released when 350 g of steam at 100 ºC condenses to water at 100 ºC?

Question 65

100 g of ice at 0 ºC is added to an insulated chamber containing 20 g of steam at 100 ºC. What is the final temperature of the 105 g of water?

Do questions

- **22-33** from chapter one of the textbook

Transferring energy

If a hot metal cube is placed into cool water, the water gets warmer and the metal cube cools down. There is a transfer of energy from the hot metal cube to the water, due to the temperature difference between the water and the cube. This transfer process is called heating. The internal energy of the metal cube decreases, while the internal energy of the water increases.

There are three ways to transfer heat; conduction, convection, and radiation.

Conduction

Conduction is the movement of heat throughout a material without carrying any of the material with it. Heat causes the particles to vibrate faster, these faster vibrations cause adjacent particles to vibrate faster. In this way heat, via the vibrations, travels.

Conduction can occur in solids, liquids or gases, but it occurs fastest in solids. Most metals are good conductors of heat, liquids and gases tend to be poor conductors of heat. In metals the presence of free electrons which move through the lattice, colliding with a series of rapidly oscillating ions transfers thermal energy very rapidly.

Substance	Thermal conductivity ($J\ s^{-1}\ m^{-1}\ K^{-1}$)
Silver	420
Copper	400
Aluminium	240
Steel	79
Ice	1.7
Glass, concrete, brick	0.8
Water	0.59
Animal muscle, fat	0.2
Paper, cardboard, wood	0.08
Wool, felt, rock-wool	0.04
Air	0.024
Down	0.019
Styrofoam	0.01

The amount of energy lost due to conduction is given by $Q = \frac{kA(T_{body} - T_{external})t}{d}$,

where Q is the amount of energy, k, the thermal conductivity, A, the area of contact, t, the time and d, the distance between the two objects.

Expansion

Materials that expand when heated, contract when cooled. Usually the change in size is too small to be noticed. But it can cause problems for train/tram lines (as they can buckle when heated). Solids expand when heated, the particles vibrate more rapidly, and take up more space, thus the particles push each other further apart.

Substance	Expansion of 1 metre bar when heated to 100 ºC
Pyrex	0.3 mm
Glass	0.9 mm
Concrete	1.0 mm
Steel	1.0 mm
Brass	2.0 mm
Aluminium	3.0 mm

Convection

Convection is the transfer of heat by the flow of particles in the heated material. Convection is the usual method for heat to travel through liquids and gases. In convection the less dense (hotter) material rises taking the heat with it.

Wind chill

A warm body exposed to still air will heat the air around it, creating a layer of warmer air around it. When there is wind this warm layer is blown away and replaced with new cooler air. The larger temperature differential means that heat transfer speeds up. This is the transfer of heat due to convection. It is similar to conduction,

$$Q = \frac{hA(T_{body} - T_{external})t}{D},$$

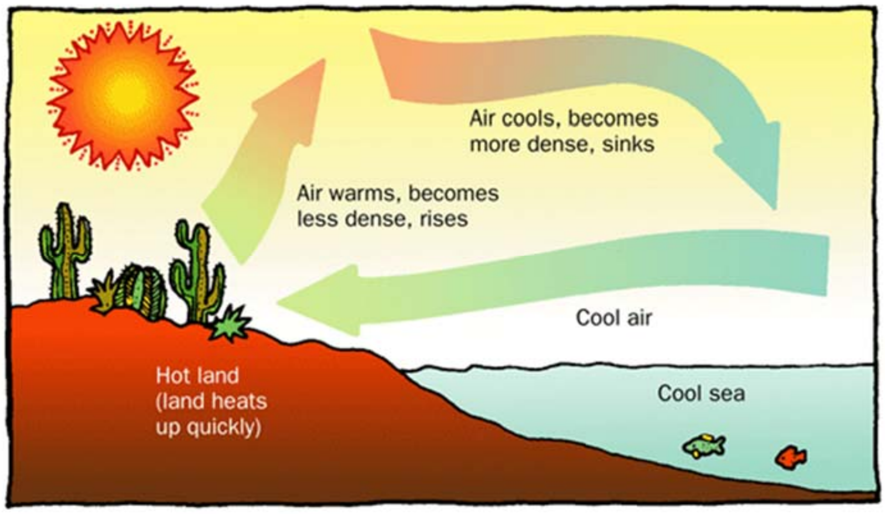
Where D is the thickness of the convection layer, h is a constant for a given situation. Both D and h are very difficult to identify.

We often use a table of “Apparent temperature” instead.

Wind speed (km hr^{-1})	**Temperature (ºC)**							
	5	**0**	**-5**	**-10**	**-15**	**-20**	**-25**	**-30**
8	2	-3	-8	-12	-18	-24	-29	-34
16	-1	-8	-14	-20	-26	-32	-39	-45
24	-4	-12	-19	-25	-33	-40	-47	-54
32	-7	-15	-22	-29	-36	-43	-50	-58
40	-9	-17	-23	-30	-38	-45	-53	-62

Convection in the atmosphere

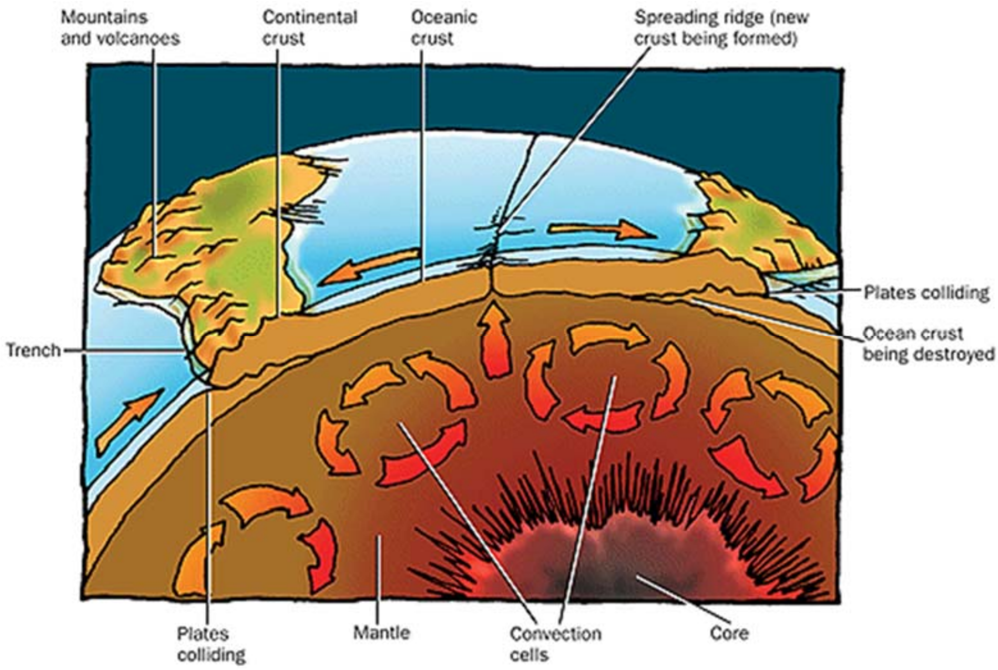
Convection also accounts for changes in temperature in the atmosphere as shown in the diagram below. As the air heats up it becomes less dense and therefore rises and new cooler air comes in to replace the hot air, creating wind.



Convection also occurs in the oceans in the same way, creating ocean currents. The oceans are the principal means by which the earth evens out its temperature. The warm seas at the equator flow towards the cold poles.

Convection in the Earth’s mantle

While convection typically only occurs in liquids and gases, convection is the force that drives tectonic shifts. The mantle is heated from below (the core), and in areas that are hotter it rises upwards, whereas in areas that are cooler it sinks down. This results in convection cells in the mantle, and produces horizontal motion of mantle material close to the Earth surface. This convection takes place in mantle rock (a mixture of silicate minerals) that at any given time would appear solid. Yet, when the forces of buoyancy are applied over millions of years, this seemingly solid material moves, behaving like an extremely viscous fluid.



Question 66

The thermal conductivity of cardboard is approximately 0.1 J s^{-1} m^{-1} K^{-1}. Suppose we place a sheet of cardboard 3.0 mm thick over an ice block at 0 ºC, and place our hand on the cardboard. How much energy will we lose by conduction from 1.0 cm^2 of our hand in 1 minute? Assume that the temperature of the hand is 30 ºC.

Question 67

A house without insulation in the roof loses a lot of energy. The heater maintains a temperature of 20 ºC inside, while outside it is 12 ºC.
The ceiling has a k value of 0.13 J s^{-1} m^{-1} $K^{-1}$and is 4.0 cm thick.
a. Calculate the energy loss if the roof area is 150 m^2.

b. Calculate the energy loss if the house is insulated with a 8.0 cm thick layer of fibreglass batts with a k value of 0.040 J s^{-1} m^{-1} K^{-1})

Question 68

The bottom of a stainless steel frypan has an area of 0.10 m^2. It is 8.0mm thick. The gas flame beneath the frypan is 250^0C hotter than the inside of the frypan.
a. How much energy is transferred to the interior every second if the conductivity of steel is 79 J s^{-1} m^{-1} K^{-1}?

b. How much energy would be transferred every second if the bottom was made of copper? (k = 400 J s^{-1} m^{-1} K^{-1})

Question 69

Why are baking dishes made from a type of glass called Pyrex?

Question 70

Concrete needs reinforcing when it is under tension. Which material, Steel, Brass or Aluminium would have the better thermal properties when used to reinforce concrete? Why?

Question 71

Calculate how much a 1000 metre length of steel railway line would expand, if it were free to, if the temperature rose by 10 ºC

Question 72

Why are electricity wires left slack when hung between poles?

Question 73

Why aren't soft drink bottles filled to the very top?

Do questions

- **1-13** from chapter two of the textbook.

Radiation

All atoms (above absolute zero) give off radiation, but depending on their temperature they give off different levels of radiation. Hot objects give off more radiation than cooler objects. This electromagnetic radiation travels at the speed of light, c, and can travel through a vacuum. This is how heat from the sun reaches earth.

An object, such as a bar radiator at 500 ºC produces mainly infra-red radiation; an object such as an incandescent light globe at 1200 ºC radiates some visible light as well as infra-red; and an object as hot as the sun at 6000 ºC radiates a significant amount of ultraviolet radiation as well as visible and infrared radiation. The gases that are found between the galaxies of our universe are at a temperature of about 3 K (-270 ºC) and radiate microwaves or radio waves.

Black matt surfaces are better absorbers than white shiny surfaces (which tend to reflect radiation).

Question 74

What change of state occurs when;

(i) water vapour forms clouds in the atmosphere

(ii) candle wax melts as it is heated

(iii) dry cleaning fluid dries on the surface of clothes that have been cleaned.

Question 75

Which states of matter are fluids?

A Solids, liquids and gases

B Gases only

C Liquids only

D Gases and liquids

Question 76

The melting points and boiling points of substances A - D are given below. Which one is **a gas at 0 °C**? ([**Substance**] Melting Point °C and Boiling Point °C.)

A -39 and 354

B -127 and -33

C 119 and 446

D 15 and 126

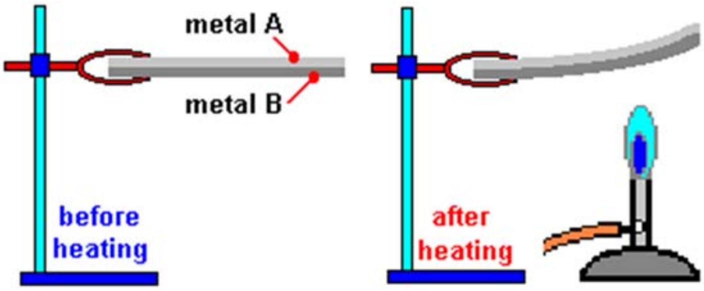
Question 77

What surfaces best absorb radiation? Select the most appropriate out of the given options.

(i) Lighter or darker?

(ii) Shinny or matte?

Question 78



Different metals expand different amounts for the same temperature rise. A bimetallic strip is made from two different metals joined together. The effect of heating a bimetallic strip is shown in the diagram. **Which pair of metals could be used in the experiment to make the strip bend downwards**?
The table below shows **the length increase in mm on heating 2 metre strips of the metals by 10 °C.**

METAL	aluminium	brass	copper	steel
length increase	0.49	0.40	0.25	0.22

A metal A = copper, metal B = aluminium

B metal A = copper, metal B = brass

C metal A = aluminium, metal B = brass

D metal A = copper, metal B = brass

For questions **79 - 88** select your answer from; Conduction, Convection or Radiation.

Question 79

What method of heat transfer occurs mainly in solids?

Question 80

What method of heat transfer can occur in a vacuum?

Question 81

What method of heat transfer occurs when particles with a lot of energy take the place of those with less?

Question 82

What method of heat transfer do we see in our weather patterns?

Question 83

What method of heat transfer explains why hot air balloons rise?

Question 84

During a house fire, the smoke and flames rise up, but the air down near the floor is cooler and less smoky. This is an example of

Question 85

When a metal spoon with a temperature of 20 °C is placed into a cup of water with a temperature of 90 °C the spoon will heat up. This is an example of:

Question 86

The transfer of heat between substances that are in direct contact with each other is called what?

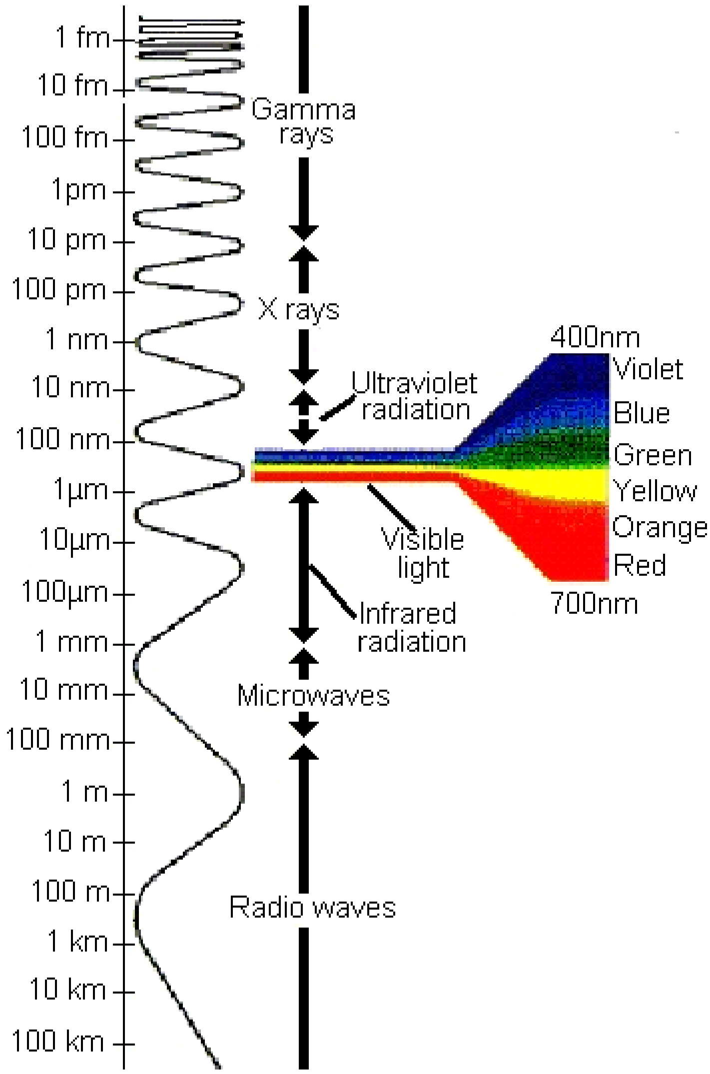
Question 87

This type of heat transfer occurs when heat moves from one molecule to another.

Question 88

This type of heat transfer transfers heat in all directions.

The electromagnetic spectrum



In a vacuum, all electromagnetic waves move at the same speed, c, the speed of light. They differ from one another in their wavelength (and thus frequency). The electromagnetic spectrum includes waves with an enormous range of wavelengths, from hundreds of kilometres to smaller than the size of the nucleus of an atom.

Visible light, in the band ~4×10^{-7} m to ~7×10^{-7} m is detected by the retina of the eye. The longer wavelengths (lower frequency waves) appear red, and the shorter wavelengths (higher frequency waves) appear violet. The limits of the visible spectrum are not well defined, because eye sensitivity drops off gradually at both long and short wavelengths. Visible light makes up less than 10^{-6}% of the measured electromagnetic (EM) spectrum. Although humans cannot see infrared radiation, they can feel it as heat.

By 1864 the Scottish physicist, James Maxwell, had worked out a mathematical theory of electromagnetism. He developed a series of equations to show that the energies of heat, light and electricity are propagated in free space (vacuum) as electromagnetic waves, their different properties being due to differences in wavelength and frequency. Such waves travel at the same speed - the speed of light. They are *transverse waves* in which the disturbance is a time variation in both an electric and a magnetic field set at right angles to each other.

Maxwell suggested that the vibrating electric charges that produced light were the electric charges in the atom. Maxwell's theory also did not require, as a necessity, the idea that light had to have a medium through which to travel. For years scientists had been searching for the medium or 'aether' through which light travelled. Maxwell's work only assumed light to be travelling in an electromagnetic field and not necessarily a 'particle medium'. This explained why light appeared to be able to travel through what scientists thought was a vacuum, but had been reluctant to believe was a complete vacuum because they thought some sort of medium was essential for light's propagation.

The shorter the wavelength (hence higher frequency) the more energy associated with the ray. From the diagram, Gamma rays have more energy than radio-waves.

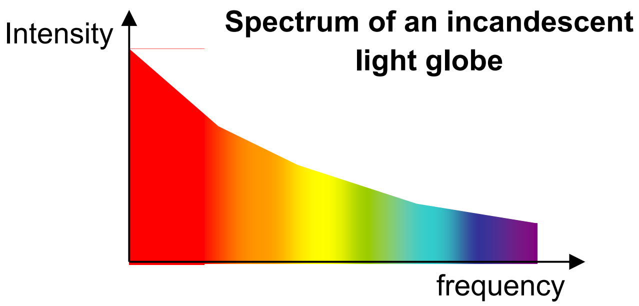
Creation of Electromagnetic Waves

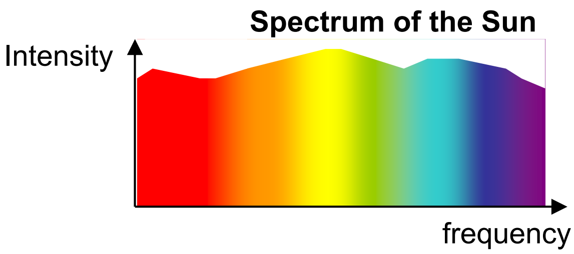
Name	Generated by	Detected by	Properties
Gamma-rays	Changes of energy levels in the nucleus	a) Photography b) Ionisation chamber	a) Penetrates matter b) Ionise gases c) Causes photo-electric emission
X-rays	Rapid deceleration of fast moving electrons (e.g. by tungsten target)		
UV	Orbital electrons of atoms. E.g. the Sun	a) Photography b) Photoelectric cell	a) Absorbed by glass b) Can cause many chemical reactions c) (e.g. the tanning of human skin) d) Ionise atoms in the atmosphere resulting in the ionosphere
Visible light	Re-arrangement of outer orbital electrons in atoms and molecules. (e.g. incandescent solids)	a) Eye b) Photography c) Photocell	Can cause chemical action
Infra-red	Outer electrons in atoms and molecules	a) Photography by special plate b) Heating effect	a) Useful for 'seeing' molecular structures b) Less scattered than visible light by atmosphere
Micro-waves	Micro-wave generators	Micro-wave receivers	a) Microwave ovens b) Radar communication
Radio Waves	Oscillating electrons in radio aerials	Tuned electric circuit	Different wavelengths find specialised uses in radio communications

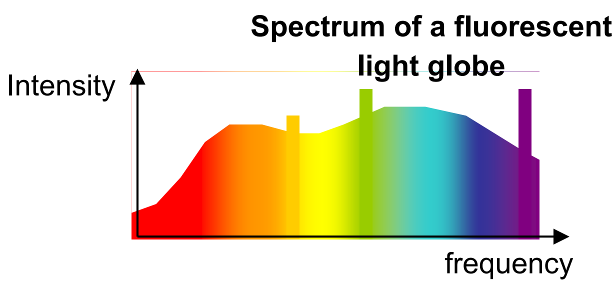
All these forms of electromagnetic radiation are effectively produced by the acceleration of charged particles.

Some Common Visible Spectra

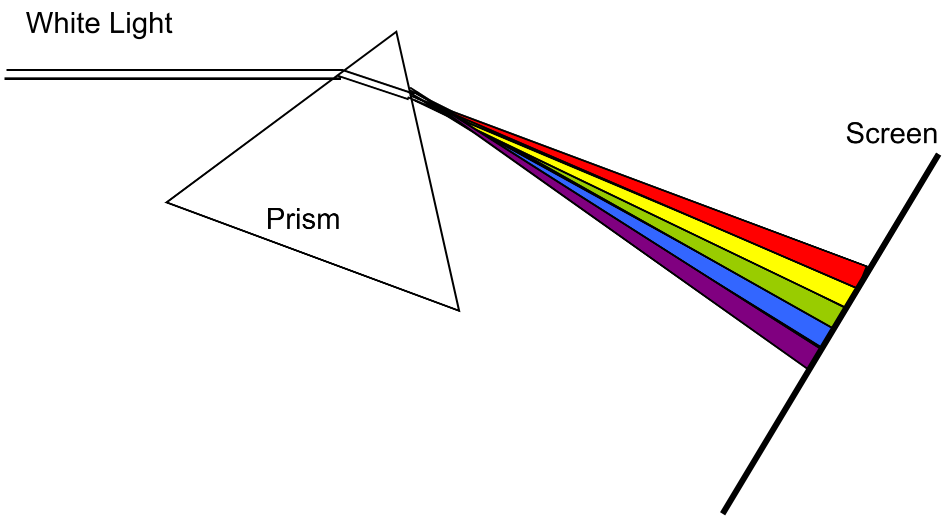
Here are some graphs showing the intensity of light emitted at different wavelengths for common sources of light. They are not to scale.







White Light
White light is made up of all of the colours of the visible spectrum. The light can be split into its constituent colours by shining it through a prism, as shown in the diagram below. These same colours are observed when you look at a rainbow.

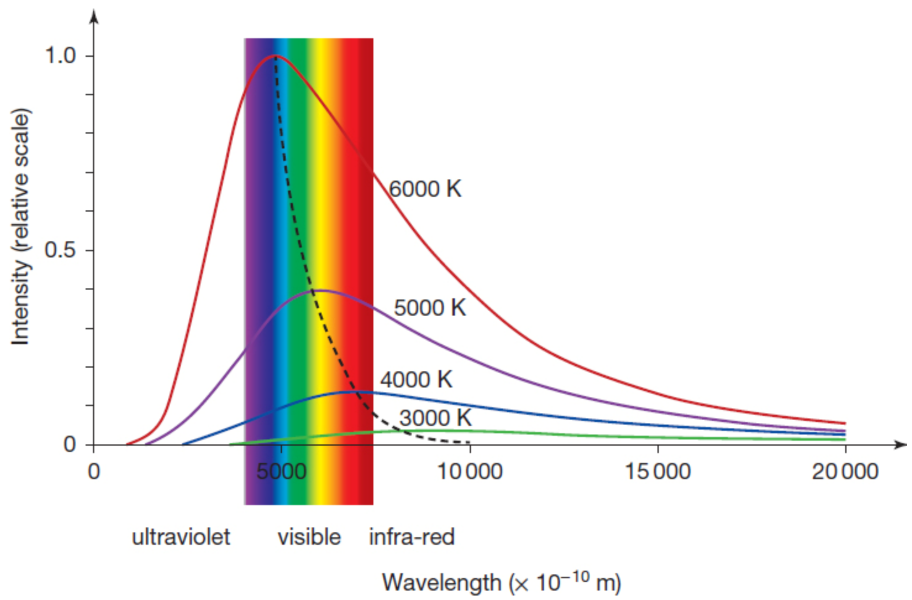


Wein's Law

The graph below shows the emission spectrums for bodies at different temperatures. The black dotted line indicates the peak emissions from a body at a certain temperature, from this it is possible to work out the temperature of an object from its emission spectrum. This relationship is known as Wein's Law and can be stated as

$$\lambda_{\max} = \frac{2.9\times10^{-3}}{T} \quad \text{or} \quad \lambda_{\max}\, T = 2.9\times10^{-3} = \text{constant}$$

Where λ_{max} = Peak emission (m) and T = surface temperature in kelvin (K)

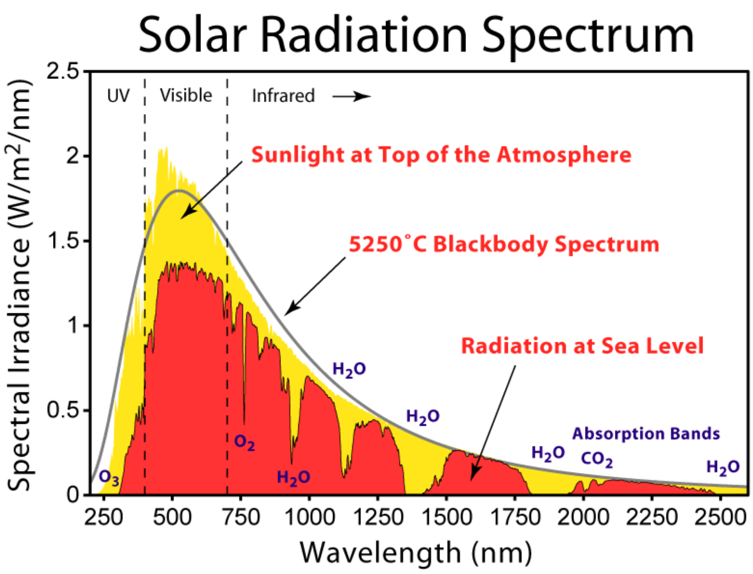


Temperature of the Sun
Thanks to the work of Max Planck and that of Wilhelm Wein we can measure the temperature of the Sun based upon its *spectrum.* All objects emit radiation on the electromagnetic spectrum, the hotter the object the shorter the length of the radiation emitted.

This is why humans can be seen to glow using an infrared camera. When we get towards very hot objects like stars and they can appear very bright and sometimes blue (shorter wavelength).

Using this information, we can take a spectrum of the Sun as shown below:

This shows that the radiation emitted from the sun is mainly ultraviolet, visible and infrared.



Using the Sun's spectrum from above we can see the peak emission of approximately 502 nm, 502 x 10^{-9} m to find the approximate surface temperature of the Sun:
Now we can employ Wien's law:

$$\lambda = \frac{2.9 \times 10^{-3}}{T}$$

$$T = \frac{2.9 \times 10^{-3}}{\lambda}$$

$$= \frac{2.9 \times 10^{-3}}{5.02 \times 10^{-9}}$$

$$= 5\,776\ \text{K}$$

Wien's law can also be used to calculate the peak wavelength of the re-radiated electromagnetic radiation from Earth.

The average temperature of the Earth is 15 ºC = 288 K.

$$\lambda = \frac{2.9\times10^{-3}}{T}$$
$$= \frac{2.9\times10^{-3}}{288}$$
$$= 1.0\times10^{-5} \text{ m}$$

Stefan-Boltzmann Law

Jozef Stefan looked for a relationship between the emissions spectrums of different bodies and found that the area under the graph was proportional to the absolute temperature to the power of 4. The area under the graph is the total energy emitted every second which is also is the power. Therefore; $P \propto T^4$.

Ludwig Boltzmann proved the relationship from a theoretical standpoint, and so this relationship is known as the **Stefan-Boltzmann Law.**

The constant of proportionality for this relationship is $\sigma = 5.67\times10^{-8}$ W m^{-2} K^{-4}, making the Stefan-Boltzmann law $\mathbf{P = \sigma T^4}$.

Question 89

One way of measuring the temperature of a star is by analysing its spectrum. A hotter star, when compared to a cooler star, will have more radiation with a;

A shorter wavelength

B longer wavelength

C the same wavelength

D a different type of wave

Question 90

Consider the human body, with a surface temperature of about or 310 K.

a. What is the wavelength at which the human body emits the most radiation?

b. What part of the spectrum in this wavelength in? *Hint: Review the wavelengths of the various sections in the electromagnetic spectrum.*

Question 91

By knowing the colour of a star, we can predict the temperature at its surface.

a. Consider a violet star, with a wavelength of 4×10^{-7} m. Use Wien's Law to determine the temperature at the surface of this star. Compare this temperature to the temperature at the surface of the sun.

b. Consider a red star, with a wavelength of 7×10^{-7} m. Use Wien's Law to determine the temperature at the surface of this star. Compare this temperature to the temperature at the surface of the sun (5800 K).

Question 92

When an iron reaches about 480 °C it begins to glow with a red colour.

a. How much more energy per second is emitted by the iron at this temperature compared to when it is at a room temperature of 20 °C?

b. How much hotter than 20 °C would the iron need to be to emit 10 times as much energy per second?

Question 93

A star has a λ_{max} of 650 nm and a radius of 700 000 km.

a. Use Wein's Law to calculate its surface temperature.

b. Calculate its surface area

c. Use Stefan-Boltzmann's law to calculate its power output.

Question 94

The electromagnetic spectrum includes the visible light we can see.

a. Which has the longest wavelength, red light or violet light?

b. Which has the most energy, red light or violet light?

Question 95

Describe what happens when you split white light.

Do questions

- **14-23** from chapter two of the textbook.

Waves

Frequency wavelength and amplitude

Most information about our surroundings comes to us in some form of waves. It is through wave motion that sounds come to our ears, light to our eyes, and electromagnetic signals to our radios and televisions. Through *wave motion*, energy can be transferred from a source to a receiver without the transfer of matter between the two points.

If a stone drops into a quiet pool of water, a disturbance is created where the stone enters the water. This disturbance spreads out to eventually reach all parts of the pool.

The stone entering the water sets into motion the particles of the water that it strikes. These particles set neighbouring particles into motion and so the disturbance is propagated (spread) through the liquid. However, no individual particle travels far from its initial position –The wave transports of energy without transporting matter. The motion of the wave through the medium is a result of the action of successive parts of the medium on each other. If the particles were completely independent of each other, no wave could pass through.

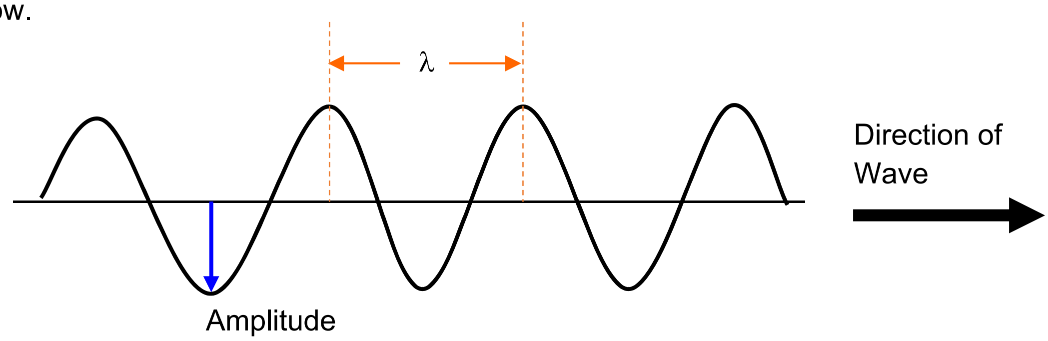
All forms of wave motion allow the transfer of energy without the net transfer of matter.

Describing Waves

Waves can be characterised by several key quantities. These are the speed, frequency, period, amplitude and wavelength of the wave.

Wavelength

The distance between two similar features (peak to peak or trough to trough) of the graph is called the wavelength (λ). This is illustrated for longitudinal and transverse waves in the diagram below.



Frequency (f)

Frequency is a measure of how rapidly the source of the wave is vibrating. The frequency (f) is defined as the number of vibrations per second. The units for frequency are Hertz, Hz, which are cycles per second.

Period (T)

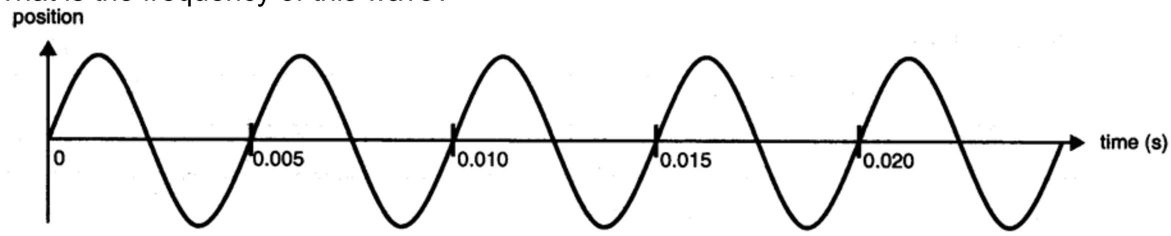
The period is the length of time required for one full cycle of the wave to be complete. Frequency is the number of cycles per second, $\therefore$ $f = 1/T$, where T is the period, the time taken for 1 cycle. Frequency is measured in Hertz or cycles per second.

Amplitude
The amplitude of a wave is the distance from the rest position to the limit of a crest or trough as shown in the diagram above. The total from crest to trough is twice the amplitude. The amplitude of the wave is an indication of the amount of energy that the wave is carrying.

Speed (c)
The speed of light in a vacuum is 3 x 10^8 m/s. For a uniform medium the speed is constant. The frequency, amplitude and wavelength of a wave do not change its speed. This is the same for all electromagnetic radiation.

Question 96

What is the frequency of this wave?



a. What is the period of this wave?

b. What is the frequency of this wave?

Question 97

If Triple M has a frequency of 105.1MHz, what is the wavelength of the signal?

Question 98

The main idea/ main process of wave motion is:

A. The production of energy

B. The transformation of energy

C. The movement of matter

D. The transfer of energy

E. The confusion of students

Climate Change

By nature, every object tries to reach a point of thermal equilibrium with its surroundings. In order to achieve this the object must emit the same amount of energy that it receives. If an object emits more energy than it receives the object will cool down, causing it to emit less energy, this will continue until it is in thermal equilibrium with its surroundings. The opposite is true if it emits less energy that it is receiving.

The Earth is also trying to achieve thermal equilibrium. The average energy received from the sun is 342 W m^{-2}, however about 100 W m^{-2} is reflected back into space by the white surfaces on Earth (e.g. clouds, ice sheets). This means that to be in thermal equilibrium the Earth must emit on average 242 W m^{-2}.

Using the Stefan-Boltzmann relationship we can determine the temperature the Earth would need to be in order to emit 242 W m^{-2} on average.

$$P = \sigma T^4$$

$$P = \sigma T^4$$

$$\backslash\ T = \sqrt[4]{\frac{P}{\sigma}}$$

$$= \sqrt[4]{\frac{242}{5.67 \times 10^{-8}}}$$

$$= 255.6\ K$$

$$= {}^{-}17.4\ ^{\circ}C$$

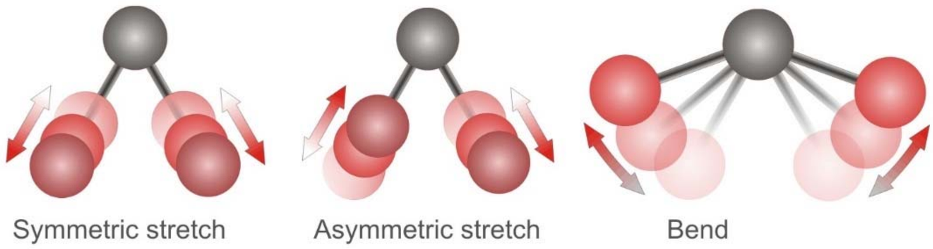
This does not mean that the average temperature of the earth is actually this temperature. Rather it is the temperature of the upper atmosphere, and neglects the effects of the atmosphere on the surface of the planet. The greenhouse gases in Earth's atmosphere (mostly water and carbon dioxide), trap heat keeping the Earth warmer.

The atmosphere's effects on the incoming solar radiation

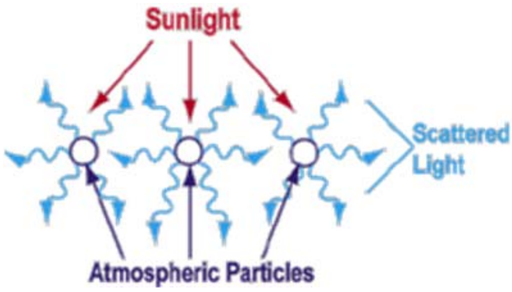
The quantities of different gases in the atmosphere can be seen in the table below. Each molecule interacts differently with the incoming solar radiation, absorbing and transmitting various parts of the spectrum. From the table it is clear that the majority of the atmosphere is made up of nitrogen and oxygen (mostly nitrogen!).

Gas	Dry Volume
nitrogen (N_2)	78.08%
oxygen (O_2)	20.95%
water vapour (H_2O)	1% - 4%
argon (Ar)	0.93%
carbon dioxide (CO_2)	0.038%
neon (Ne)	0.002%
helium (He)	0.0005%
methane (CH_4)	0.0002%
hydrogen (H_2)	0.00005%
nitrous oxide (N_2O)	0.00003%
ozone (O_3)	0.000004%

Molecules made up of two atoms, like nitrogen and oxygen, will absorb and re-emit ultraviolet radiation, but transmit visible and infrared radiation leaving their paths unaltered. Molecules with three atoms are more flexible than those with two atoms, and have three different ways of stretching or bending (as shown by the diagrams below), as well as oscillations around three axes. This allows molecules such as water and carbon dioxide to absorb and re-emit infrared radiation. Methane, with five atoms, is even more flexible. These molecules absorb different parts of the infrared spectrum, and so contribute independently to the greenhouse effect.

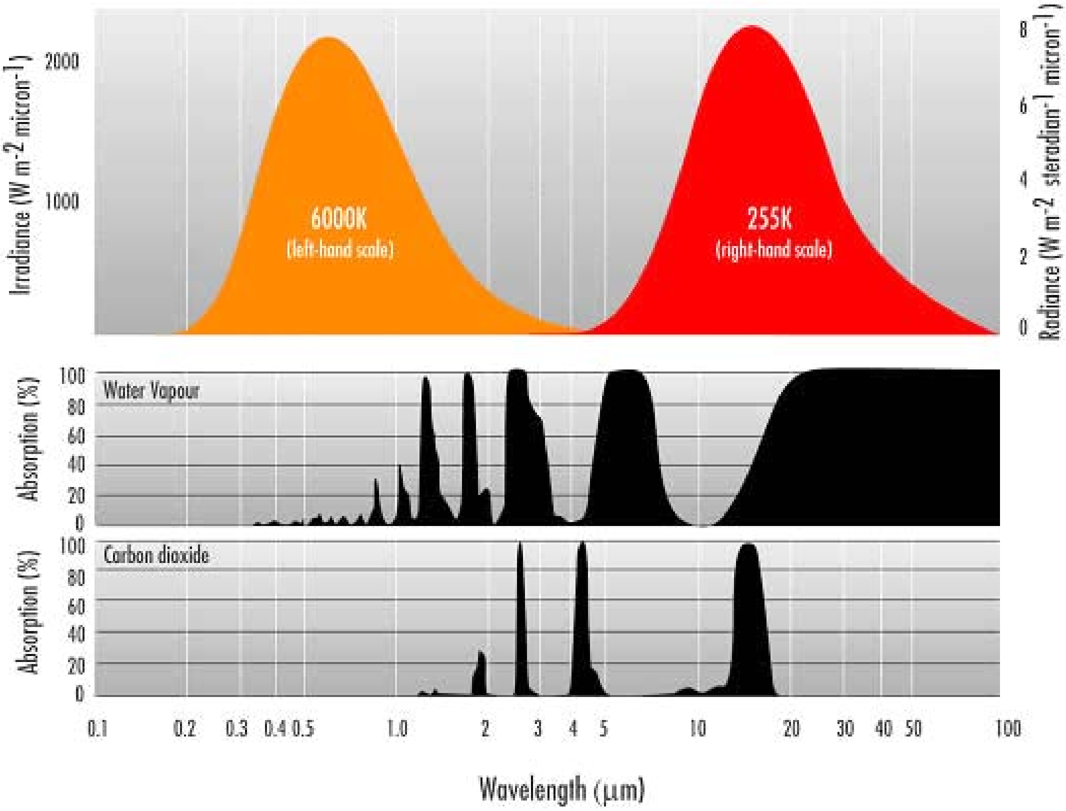


When a molecule has absorbed radiation it re-emits it, however it does this in a random direction. This means that the nitrogen and oxygen (and ozone) in the atmosphere scatter the ultraviolet radiation coming from the sun. The radiation that is scattered back out into space continues in that direction, but the radiation that is scattered toward Earth is likely to be absorbed and re-emitted by parts of the atmosphere closer to the Earth, to be scattered further. Therefore, only a very small amount of the ultra violet radiation coming from the sun reaches the Earth's surface, which is lucky as otherwise it would be very difficult for life on Earth to survive.

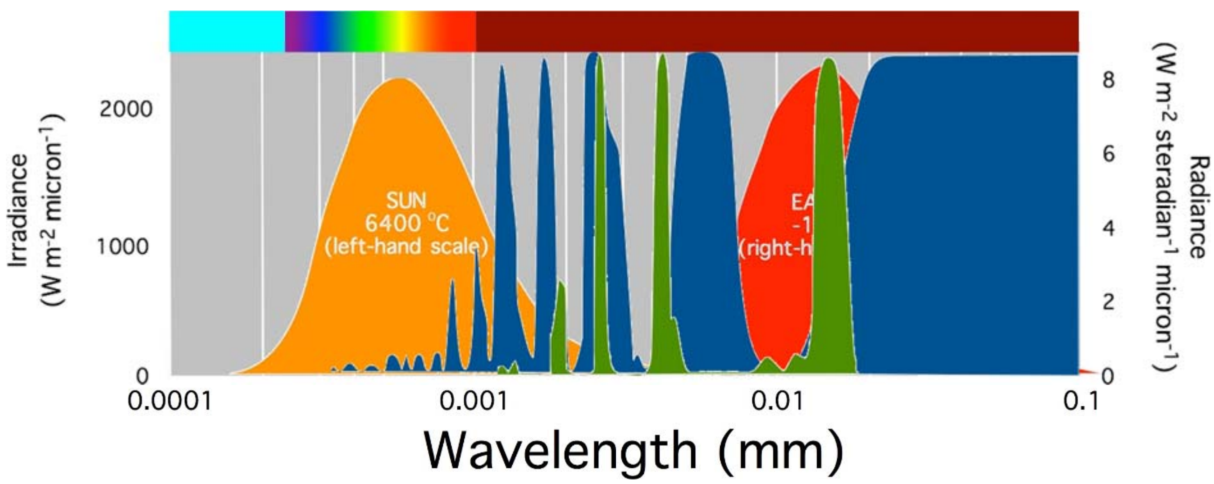


The greenhouse gases do the same thing with the infrared radiation being emitted by the Earth, scattering the radiation so more than half of the infrared radiation being emitted by the Earth is reflected back down to Earth, keeping it warm. Again, this is useful, as otherwise the Earth would be very cold. However, it is also important that the Earth doesn't get too hot!

The graphs below show the radiation that reaches the Earth from the Sun (top left), the radiation that the Earth emits (top right), and the absorption spectra for water (middle) and carbon dioxide (bottom).



Overlaying the two absorption spectra on the emission spectra it can be seen that the combination of water and carbon dioxide in the atmosphere blocks a significant amount of the outgoing radiation.

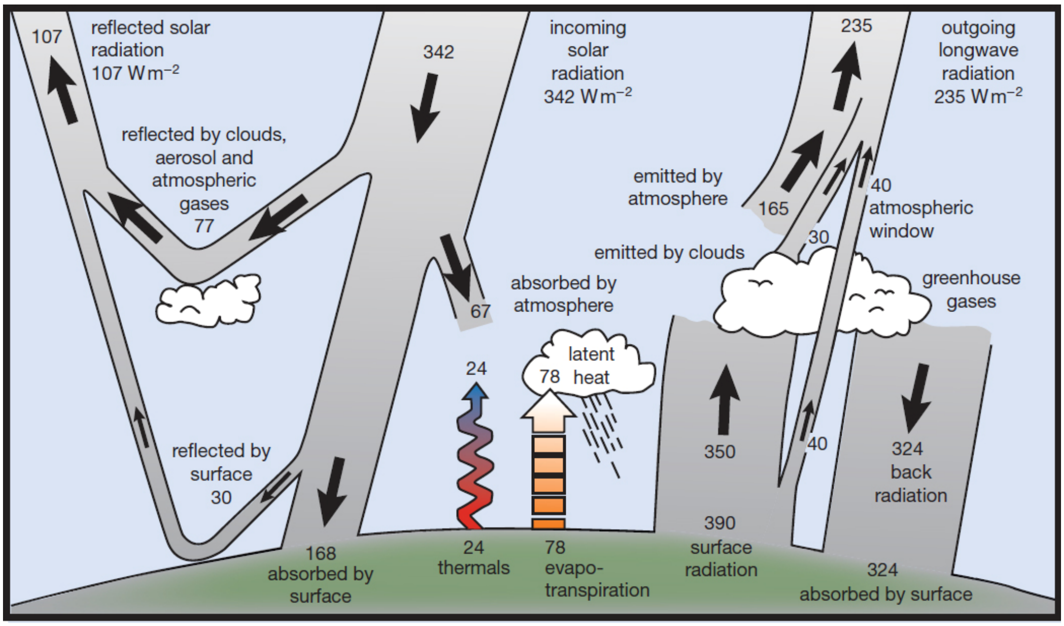


All parts of the Earth's climate interact, so changing one thing has effects on everything else, this is known as feedback. For example, as the Earth heats up ice caps melt, reducing how much radiation is initially reflected back into space. As the oceans warm up more water vapour enters the atmosphere, increasing the greenhouse effect. These are examples of positive feedback, as the effects add to the cause (more heat!). Negative feedback is where the effect aims to do the reverse of the cause (cooling the planet down). For example, as the Earth heats up more it emits more radiation in order to cool the Earth. However, if there are too many greenhouse gases in the atmosphere it is difficult for this radiation to escape.

An everyday example of feedback is when a microphone is placed too close to its speaker, the sound through the microphone is amplified and played through the speaker, which is picked up by the microphone, amplified and so on, which creates a loud, high pitched noise.

The risk in a feedback loop is that there is a tipping point beyond which the system cannot restabilise. An example of this is Venus' atmosphere with its runaway greenhouse effect. Venus' atmosphere is about 90 times thicker than Earth's and is 96% carbon dioxide. The temperature at the surface of Venus is 740 K (467 °C).

The diagram below shows where energy comes from and goes to, showing the complex nature of the Earth's climate. Changing any one of the numbers in the diagram will have an effect in numerus other places.

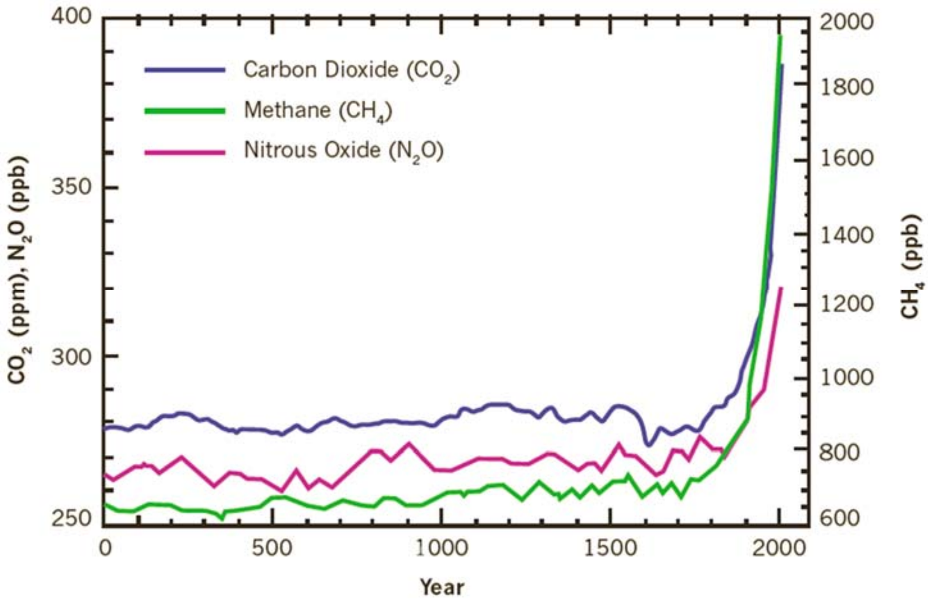


Do questions

- **1-13** from chapter three of the textbook.

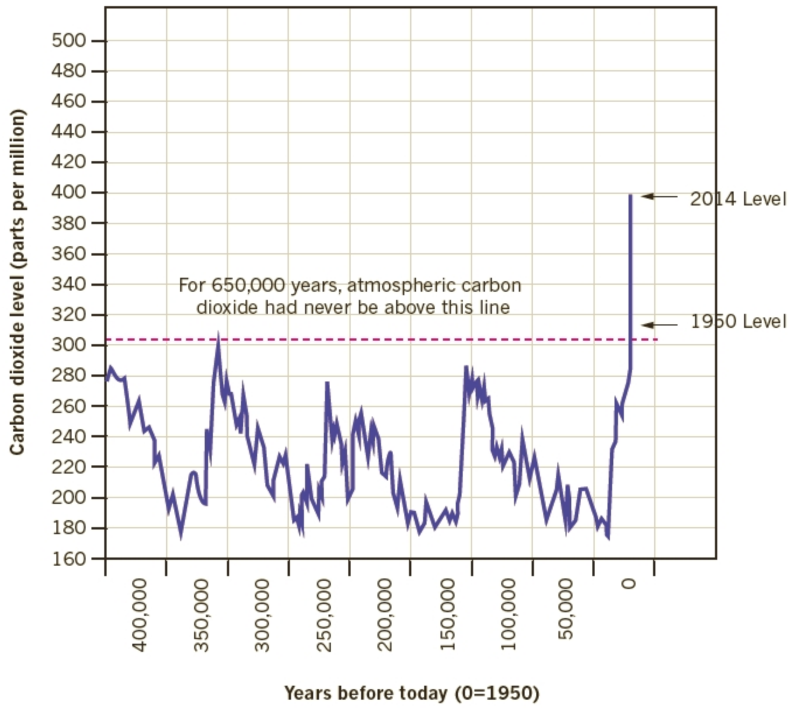
The human contribution to global warming

While humans are not the biggest cause of the greenhouse gasses, the human contribution on top of the natural fluctuations mean that there are now more greenhouse gases in the atmosphere than there have been in the last 400 000 years. Human activities such as the burning of fossil fuels, agriculture and clearing land all increase the concentrations of greenhouse gases in the atmosphere. The top graph on the following page shows the levels of different greenhouse gases over the last 2000 years, showing a significant increase in all the greenhouse gases from the 1700s onward (around the beginning of the industrial era).



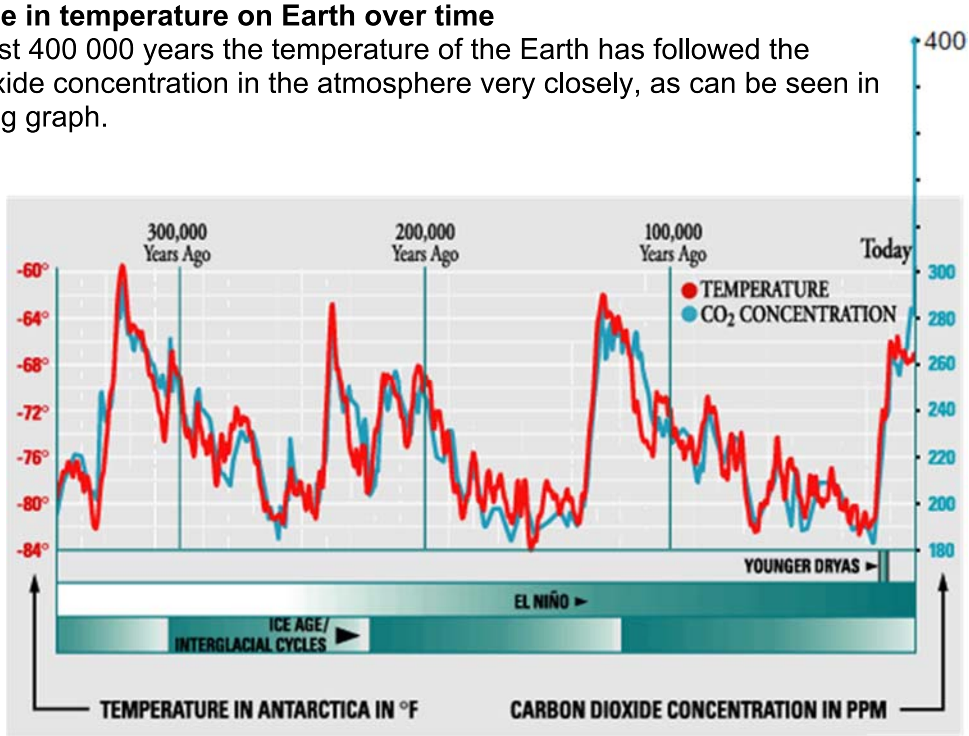
The following graph shows carbon dioxide levels in the atmosphere for the past 400 000 years (about the time that modern humans evolved). It shows that while the carbon dioxide levels fluctuate considerably over long timespans, the current levels are considerably higher than modern humans have ever seen. If the Earth becomes too hot changes will occur across the entire planet that will significantly affect the Earth's ability to sustain the current way of life.

Large numbers of buildings also help to keep the heat in, adding to the Earth's temperature.

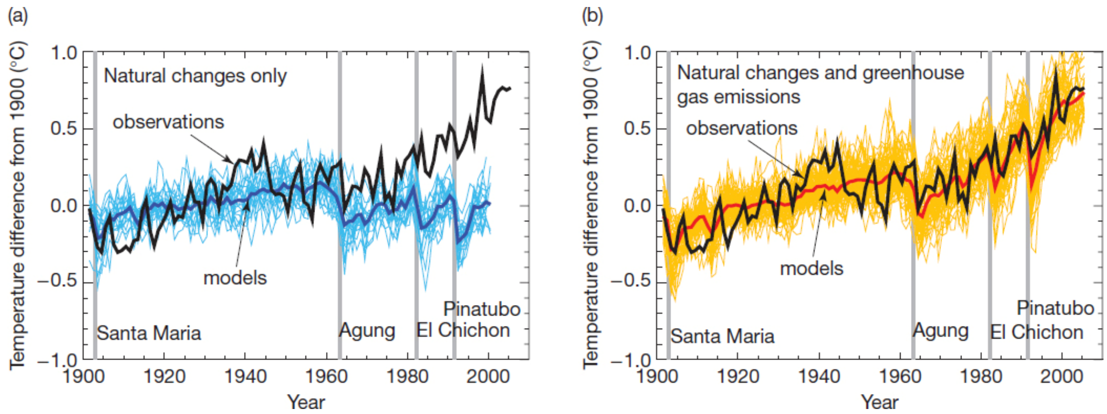


The change in temperature on Earth over time

Over the last 400 000 years the temperature of the Earth has followed the carbon dioxide concentration in the atmosphere very closely, as can be seen in the following graph.



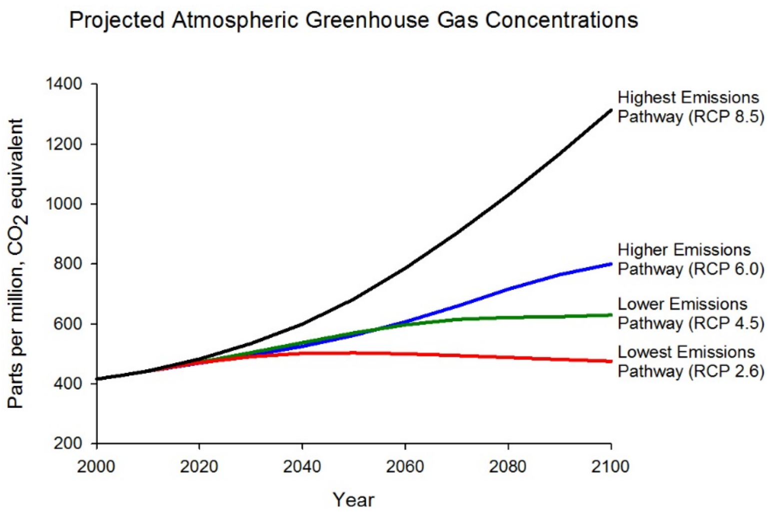
To investigate this further, we can look at the more recent history to see how well climate models fit the observed data. Climate models attempt to calculate future trends and account for past observations. The solid black line on both the graphs below shows the global average surface air temperature. The graph on the left shows what climate models predict would have happened if greenhouse gas levels remained constant from 1900. The solid blue line is the average of numerous models. The graph on the right depicts the same models, but this time with updated greenhouse gas levels. This suggests that the increasing levels of greenhouse gases in the atmosphere has led to an increase in global temperatures.



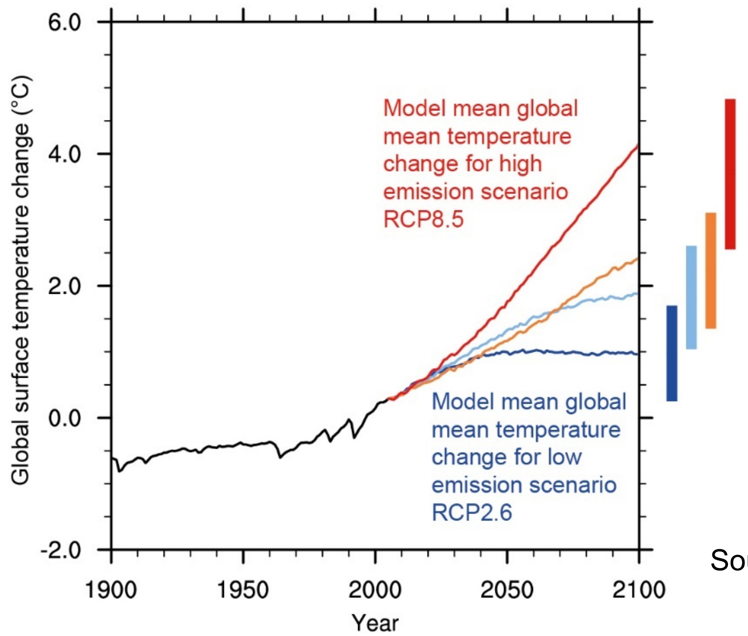
Models like these ones can be used to make predictions into the future about temperature changes and to investigate how long the Earth's atmosphere would take to respond to significant reductions in greenhouse gas emissions.

Studies predict that even if carbon dioxide emissions were cut to zero tomorrow, the carbon dioxide in the atmosphere would continue to heat the Earth for hundreds of years.

The graph below shows projected greenhouse gas concentrations for four different emissions pathways. The top pathway assumes that greenhouse gas emissions will continue to rise throughout the current century. The bottom pathway assumes that emissions reach a peak between 2010 and 2020, declining thereafter.



How the temperature of the planet will look in the future depends on our ability to cut greenhouse gas emissions. The graph below shows predicted changes to the mean surface temperature, based on the emission on the pervious page. The vertical bars at right show likely ranges in temperature by the end of the century, while the lines show projections averaged across a range of climate models. Changes are relative to the 1986-2005 average.



Source: [IPCC, 2013]

Do questions

- **14-25** from chapter three of the textbook.

2014, 2015 and 2016 where hottest years on record since records have been kept (1880)

Investigate more in depth

Create a 5-minute presentation on one of the following (or come up with your own topic on climate change to investigate – make sure to have it approved)

- Compare domestic heating and cooling technologies. Are the brochures and advertising physically plausible?
- Investigate the design of energy efficient houses. How do building materials differ? Are star ratings reliable? Should design features such as double glazing and orientation in relation to the Sun be mandatory?
- Compare appliances by their technology, efficiency and emissions. Are the energy ratings useful?
- Research solar thermal technology. Is generating electricity by solar thermal technology a feasible alternative for Australia?
- Investigate geo-engineering solutions to tackle climate change. Are any of them feasible?
- Examine the treatments for hypothermia (body core temperature < 35 °C) and hyperthermia (body core temperature > 38 °C). How have they changed over time and how do they work?
- Compare different technologies for food preparation, e.g. microwave oven vs convection oven as well as different fuel options.

These broad topics may need to be narrowed down to focus on a specific aspect if the task is to be manageable.