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IGCSE PHYSICS 0625 · TOPICAL PAST PAPERS

Transfer of Thermal Energy — Paper 2

Worked Solutions (Theory / Structured)

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Transfer of Thermal Energy — Paper 2 · Worked Solutions

Megalecture worked solutions — model answers with working; please verify before classroom use. These solutions cover the structured (Paper 2 / theory) topical compilation on **Transfer of Thermal Energy (IGCSE Physics 0625)**: conduction, convection, radiation, good and bad emitters/absorbers, experiments and everyday applications, plus the occasional numerical part. Each answer lists clear marking points; numerical finals are shown in **bold with units**. Take the speed of light $c = 3.0 \times 10^8$ m/s where a radiation-travel-time calculation is required.

Conduction · Convection · Radiation — Structured Questions

Question 1 — May/June 2003 P2 Q10 (water heaters)

Two electric water heaters hold the same amount of water. Fig. 10.1 (less efficient) has a grey plastic case with an air gap; Fig. 10.2 (more efficient) has insulation and a white plastic case.

(a)(i) What happens to the molecules of the plastic case during conduction. [part of 2]

- The hot inner surface gives energy to the case molecules, which **vibrate more (with greater amplitude / kinetic energy)**.
- These molecules collide with / pass energy to neighbouring molecules, so the vibration (and energy) is passed from the hot side to the cooler outer side, with the molecules staying in fixed positions.

(a)(ii) What happens to the molecules of the air outside the heater during convection.

- Air next to the warm case is heated, **expands and becomes less dense**, so it rises.
- Cooler, denser air moves in to take its place and is heated in turn, setting up a circulating **convection current** that carries energy away.

(b)(i) How the heater in Fig. 10.2 reduces energy lost by conduction, convection and radiation. [part of 5]

- **Conduction:** the layer of insulation (a poor conductor, trapping air) greatly reduces the rate energy is conducted out through the wall.
- **Convection:** trapped air in the insulation cannot circulate, so it cannot carry energy away by convection; the outer case stays cooler so it heats the surrounding air less.
- **Radiation:** the white (shiny, light-coloured) outer case is a **poor emitter of infra-red radiation**, so it radiates away less energy than the grey case.

(b)(ii) Two advantages of using an efficient water heater in a kitchen.

- The water stays hot for longer / less electrical energy is needed to keep it hot, so it is **cheaper to run**.
- The outer case stays cooler, so it is **safer to touch** (and wastes less energy / less heating of the kitchen).

Question 2 — May/June 2004 P2 Q2 (Sun, match, fibreglass)

(a)(i) Method that transfers heat from the Sun to the Earth. [part of 2]

Radiation (infra-red / electromagnetic radiation).

(a)(ii) Why the other two methods cannot be involved.

- Conduction and convection both need a **material medium (particles)** to carry the energy.
- Between the Sun and the Earth there is a **vacuum (empty space) with no particles**, so neither conduction nor convection can take place — only radiation can travel through a vacuum.

(b) How convection makes a hand above a lighted match feel hot. [2]

- The flame heats the air just above it; this air **expands, becomes less dense and rises**.
- The rising warm air reaches the hand above the match and transfers thermal energy to it, so the hand feels hot. (Cooler air flows in below to replace it.)

(c) How fibreglass between ceiling and roof keeps the room warm. [2]

- Fibreglass **traps air** in its fibres; trapped air is a **very poor conductor** of heat, so it reduces the rate energy is conducted from the warm room up into the cold roof space.
- Because the air is trapped it cannot circulate, so energy is not carried away by convection either; less energy escapes, so the room stays warmer.

Question 3 — May/June 2004 P2 Q9 (electric grill)

An electric grill has a red-hot heating element that emits visible light and infra-red radiation to cook the food; a layer of shiny material lies between the element and the outer case.

(a)(ii) Why the grill has a layer of shiny material between the heating element and the outer case. [2]

- The shiny surface is a **good reflector (and poor absorber) of infra-red radiation**, so it reflects the radiation from the element back towards the food instead of letting it pass to the case.
- This keeps the outer case cooler / safer and directs more energy onto the food, making the grill more efficient.

Note: only part (a)(ii) appears in this topical compilation; part (a)(i) is not reproduced.

Question 4 — Oct/Nov 2005 P2 Q10 (heat loss from a house)

Fig. 10.1: roof loss (to be found), windows 10 %, walls 35 %, escape of hot air 15 %, floors 15 %.

(a)(i) Percentage of energy lost through the roof. [1]

The five losses must total 100 %: roof = 100 − (10 + 35 + 15 + 15) = 100 − 75.

Final: roof loss = 25 %.

(a)(ii) How energy is lost through the roof by conduction and by radiation. [part]

- **Conduction:** warm inside surface heats the roof material; its particles vibrate more and pass energy through to the cold outside surface.

- **Radiation:** the warm outer surface of the roof **emits infra-red radiation** into the cooler surroundings, carrying energy away.

(a)(iii) How fitting carpets on the floor reduces energy loss. [2]

- A carpet (and the air trapped in its fibres) is a **poor conductor / good insulator**.
- It reduces the rate energy is conducted from the warm room through the floor, so less energy is lost.

(b)(i) Values of X and Y in the cost table. [2]

The table compares: A — fitting carpets, £600, £10 saved/yr, payback 60 yr; B — insulating the roof, £300, £Y saved/yr, payback 3 yr; C — fitting modern windows, £X, £20 saved/yr, payback 40 yr.

Years to recover = cost ÷ annual saving.

For B: $3 = 300 \div Y \Rightarrow Y = 300 \div 3 =$ **£100 per year**.

For C: $40 = X \div 20 \Rightarrow X = 40 \times 20 =$ **£800**.

Final: X = £800, Y = £100.

(b)(ii) Which method the house owner should choose, with reason. [part]

Insulating the roof (B): it has the shortest payback time (3 years), so it recovers its cost soonest / saves money fastest.

(b)(iii) Two other ways of reducing energy loss (not already mentioned). [part]

- Insulate the walls (cavity-wall insulation).
- Draught-proof / seal gaps around doors to stop the escape of hot air (or fit insulation under the floor).

Question 5 — May/June 2008 P2 Q3 (marathon runner, foil blanket)

(a)(i) How evaporation helps the runner lose energy (use ideas about molecules). [2]

- The **faster-moving (most energetic) water molecules** on the skin escape from the surface (evaporate).
- This leaves behind slower molecules with lower average kinetic energy, so the **temperature of the skin falls** — energy is carried away by the escaping molecules, cooling the runner.

(a)(ii) Why hot air rises around the runner. [1]

Air warmed by the runner expands, becomes less dense than the surrounding air and so rises (convection).

(b) How the shiny foil blanket reduces energy losses (conduction, convection, radiation). [3]

- **Radiation:** the shiny silver surface is a **poor emitter of infra-red radiation**, so the runner radiates away much less energy; it also reflects radiation back to the body.
- **Convection:** the blanket stops warm air around the body from being carried away, and traps a layer of air so convection currents cannot remove energy.
- **Conduction:** the trapped layer of (still) air is a poor conductor, reducing energy conducted away from the body.

Question 6 — May/June 2009 P2 Q2 (pan of water on a hotplate)

(a)(i) Method of heat transfer through the metal pan. [1]

Conduction.

(a)(ii) How the molecules transfer heat through the metal pan. [1]

- Heated metal particles **vibrate more vigorously** and pass energy to neighbouring particles by collisions; also the metal has **free (delocalised) electrons** that move, gain kinetic energy and carry it quickly through the metal to the cooler parts.

(b)(i) Arrow showing the direction of movement of the water at point X. [1]

An arrow pointing upwards (water above the hot base rises).

(b)(ii) Why the water moves in this direction. [3]

- Water at the bottom is heated by the hotplate, so it **expands and becomes less dense**.
- The less-dense warm water **rises**; cooler, denser water sinks to take its place.
- This sets up a **convection current** that circulates and warms all the water.

Question 7 — May/June 2010 P22 Q3 (metal roof facing the Sun)

(a) Means by which heat is transferred from the Sun to the Earth, and why other means are not involved. [2]

- Transfer is by **radiation** (infra-red / electromagnetic radiation).
- Conduction and convection need particles / a material medium; there is a **vacuum between the Sun and the Earth**, so only radiation can cross it.

(b) How thermal energy is transferred through the metal roof from the heated surface. [2]

- By **conduction**: the heated metal particles vibrate more and pass energy to neighbours; the metal's **free electrons** gain kinetic energy and move through the metal, quickly carrying energy from the hot (sunlit) surface to the cooler underside.

Question 8 — May/June 2012 P22 Q3 (bedroom & air conditioner)

Bedroom 18 °C, main room 22 °C, outside 32 °C. Thermal inputs in one hour: through door/walls from main room 50 000 J; through walls from outside 2 000 000 J; through window 1 000 000 J; from sleeping person 250 000 J.

(a) Why more thermal energy enters from outside the house than from the main room. [1]

The temperature difference between the bedroom and the outside (18 → 32 °C = 14 °C) is much larger than between the bedroom and the main room (18 → 22 °C = 4 °C), so heat flows in faster from outside. (The wall area to the outside is also larger.)

(b)(i) Total thermal energy removed by the air conditioner in one hour. [1]

To keep the temperature constant, it must remove all the energy that enters:

Total = 50 000 + 2 000 000 + 1 000 000 + 250 000 = 3 300 000 J.

Final: thermal energy removed = 3 300 000 J (3.3×10^6 J).

(b)(ii) Electrical energy input to the air conditioner in 1 hour (power 300 W). [2]

energy = power × time; 1 hour = 60 × 60 = 3600 s.

E = 300 × 3600 = 1 080 000 J.

Final: electrical energy = 1 080 000 J (1.08×10^6 J).

(c) How cooling the air at the top of the room sets up a convection current. [3]

- The cooled air **contracts and becomes more dense** than the surrounding air.
- This denser cold air **sinks** towards the floor.
- Warmer, less-dense air rises to take its place and is cooled in turn, so a continuous **convection current** circulates and cools the whole room.

Question 9 — May/June 2013 P22 Q11 (cup of water cooling)

A small electrical heater is switched off and the water in the cup cools.

(d) Describe and explain how convection in the air causes the water to cool. [2]

- Air in contact with the warm water/cup is heated, so it **expands, becomes less dense and rises**, carrying energy away from the water.
- Cooler, denser air moves in to replace it and is heated in turn, setting up a **convection current** that continually removes thermal energy, so the water cools.

Note: only part (d) of this question appears in the topical compilation.

Question 10 — May/June 2014 P22 Q10 (white vs black saucepans cooling)

Identical saucepans of hot water cool: pan A is white, pan B is black; both uncovered. Pan B cools faster.

(a)(i) How the water in a pan loses heat by conduction. [2]

- Energetic water particles pass energy to the metal of the pan and to the air at the surface by collisions; the metal particles (and free electrons) carry energy through the pan wall to the outside, where it is lost.

(a)(ii) How the water loses heat by convection. [2]

- Warm water at the surface (and warm air just above it) **expands, becomes less dense and rises**, carrying energy away.
- Cooler, denser fluid moves in to replace it, setting up a convection current that removes energy from the water.

(b)(i) Why pan B (black) cools faster than pan A (white). [1]

A black surface is a better emitter of infra-red radiation than a white surface, so pan B radiates energy away faster.

(b)(ii) How Fig. 10.1 differs when the pans are covered. [2]

- Both pans cool **more slowly** (the curves fall less steeply / stay higher).
- A lid reduces heat loss by convection and evaporation from the water surface, so less energy escapes.

Question 11 — May/June 2015 P21 Q10 (beaker of hot water, thermometer in air)

A beaker holds pure water at 80 °C; a thermometer at room temperature is held in the air just above the water and its reading rises slowly.

(c)(i) How convection in the air causes the thermometer reading to increase. [1]

Warm air above the water rises (it is less dense), passing over the thermometer bulb and transferring thermal energy to it, so the reading increases.

(c)(ii) How water in the gas state gives thermal energy to the thermometer when the water boils. [2]

- Steam (water vapour) rises and **condenses on the cool thermometer bulb**.
- As it condenses it releases its **latent heat** (energy), giving thermal energy to the thermometer, so the reading rises quickly.

Question 12 — May/June 2016 P21 Q10 (liquid nitrogen in a vacuum flask)

Liquid nitrogen (boiling point −196 °C) is stored in a vacuum flask with two glass walls and a vacuum between them.

(b)(i) Where evaporation occurs. [1]

At the surface of the liquid nitrogen (the top surface of the liquid).

(b)(ii) Advantage of the vacuum between the two glass walls. [3]

- A vacuum contains **no particles**, so heat cannot pass through it by **conduction or convection**.
- This greatly reduces energy entering the flask, so the nitrogen warms up and boils away more slowly.
- (Only radiation can cross the vacuum, which is why the glass walls are usually silvered to reduce that too.)

Question 13 — May/June 2017 P21 Q3 (coffee cup on a warming plate)

A metal cup of coffee stands on a metal warming plate that contains a small electrical heater.

(a) How heat is transferred through the metal and to all the liquid in the cup. [3]

- Through the **metal** (plate and cup base): by **conduction** — particles vibrate more and free electrons carry energy from the hot plate up to the coffee.
- Through the **coffee**: by **convection** — heated coffee at the bottom expands, becomes less dense and rises; cooler coffee sinks, setting up a convection current that warms all the liquid.

(b) Why coffee in Fig. 3.2 (different heater) does not stay as warm as in Fig. 3.1. [1]

In Fig. 3.2 the heater is placed at the side/top rather than under the base, so it cannot set up a convection current that circulates through all the coffee — only the top is warmed, so the bulk of the coffee stays cooler.

(c)(i) Which colour of surface (black, white, dull, shiny) is best to keep the coffee warm. [1]

Shiny (a shiny surface is the poorest emitter of infra-red radiation, so least energy is radiated away).

(c)(ii) Reason for the answer to (c)(i). [1]

A shiny (light/silvered) surface is a poor emitter of infra-red radiation, so it radiates away the least energy and keeps the coffee warm longest.

Question 14 — May/June 2019 P22 Q10 (soldering iron)

A soldering iron has a heating element that raises a metal tip to a working temperature of 380 °C.

(c)(i) Describe, in terms of free electrons, how heat transfers through the metal tip. [2]

- The metal contains **free (delocalised) electrons**; at the hot end they gain kinetic energy and move faster.
- They **diffuse / move through the metal and collide** with particles (and other electrons) at the cooler end, transferring kinetic energy quickly and warming the whole tip.

(c)(ii) Explain how convection occurs in the air around the tip. [2]

- Air next to the hot tip is heated, so it **expands, becomes less dense and rises**.
- Cooler, denser air moves in to replace it and is heated in turn, forming a **convection current** that carries energy away from the tip.

Question 15 — May/June 2015 P21 Q4 + expansion (glass & iron conduction)

Glass is a poor conductor of heat; iron is a good conductor.

(a) Using ideas about particles, how conduction takes place in glass and in iron, and why iron is better. [4]

- **Conduction in glass:** heated particles vibrate more vigorously and pass energy to neighbouring particles by collisions; glass has **no free electrons**, so energy travels only by this slow particle-to-particle vibration — glass is a poor conductor.
- **Conduction in iron:** particles also vibrate and pass energy on, but iron (a metal) also has many **free (delocalised) electrons** that gain kinetic energy and move quickly through the metal, transferring energy rapidly.
- Because of these free electrons, iron conducts heat **much faster** than glass — so iron is the better conductor.

(b)(ii) How heat is transferred throughout the water in the heated glass flask. [2]

- By **convection**: water at the bottom is heated, expands, becomes less dense and rises; cooler denser water sinks to replace it.
- This sets up a circulating **convection current** that transfers heat throughout the water.

Note: the topical compilation reproduces part (a) and the expansion part (b)(ii) of this question.

Question 16 — May/June 2020 P22 Q5 (microwave oven heating soup)

Soup (mostly water) is heated in a glass bowl in a microwave oven; microwaves are absorbed in the first few centimetres of water and the metal walls reflect the microwaves.

(b)(i) Why the choice of material for the container is important in microwave cooking. [1]

The container (glass) must not absorb the microwaves (it lets them pass through to the soup); a metal container would reflect the microwaves and could not be used.

(b)(ii) Name and describe the two processes that spread thermal energy throughout the soup after the oven is switched off. [3]

- **First process — convection:** the heated outer water expands, becomes less dense and rises, while cooler denser water sinks, setting up a convection current that mixes warm and cold soup.
- **Second process — conduction:** energetic water particles collide with neighbouring (cooler) particles, passing energy on, so energy reaches the centre of the soup; the centre therefore becomes hot a few minutes after the oven is turned off.

Question 17 — May/June 2021 P21 Q2 (hollow metal cube, radiation)

A hollow metal cube of boiling water has four vertical faces of different colour/texture; a thermal-radiation sensor a fixed distance away gives the meter readings 40, 60, 80, 100.

(a) Link each type of surface to its meter reading (dull black already linked). [2]

- **Dull black** → **100** (best emitter of radiation, highest reading).
- **Shiny black** → **80** (already drawn for you).
- **Dull white** → **60**.
- **Shiny white** → **40** (worst emitter, lowest reading).

Order of emission (best to worst): dull black > shiny black > dull white > shiny white.

(b) How the hot surfaces produce a convection current in the air. [3]

- Air next to the hot faces is heated, so it **expands and becomes less dense**.
- The less-dense warm air **rises**.
- Cooler, denser air moves in to replace it and is heated in turn, forming a continuous **convection current**.

Question 18 — Oct/Nov 2002 P2 Q5 (power-station boiler & precipitator)

Hot gases rise past metal pipes in a boiler and warm the water inside them.

(a)(i) Why the hot gases rise. [part of 3]

The hot gases are less dense than the surrounding cooler gas/air, so they rise (convection).

(a)(ii) How energy passes through the metal pipes by conduction (use ideas about particles). [part of 3]

- The hot outer surface gives energy to the metal particles, which **vibrate more** and pass energy on by collisions.
- The metal's **free electrons** gain kinetic energy and move through the metal, quickly carrying energy to the inner surface and so to the water.

(b) How the electrostatic precipitator works. [3]

- Dust and ash particles pass the **negatively-charged fine wires** and become **negatively charged** (gain electrons / by induction).

- The charged dust is then **attracted to the positively-charged plates** (opposite charges attract).
- The dust sticks to the plates and is collected (removed by tapping), so clean gas leaves the chimney.

Question 19 — Oct/Nov 2003 P2 Q9 (refrigerator)

Inside the ice-box a liquid boils and takes in latent heat; the gas condenses in the black metal fins at the back, where energy leaves.

(b)(i) How the ice box at the top keeps the whole food compartment cool. [part of 4]

- Air around the ice box is cooled, so it **contracts, becomes more dense and sinks** to the bottom.
- Warmer, less-dense air rises to the ice box and is cooled in turn, setting up a **convection current** that cools the whole compartment.

(b)(ii) Why the fins are black. [part of 4]

A black surface is a good emitter of infra-red radiation, so the fins radiate the unwanted heat away to the surroundings as efficiently as possible.

Question 20 — Oct/Nov 2004 P2 Q8 (heat pipe with black fins)

A heat pipe transmits energy along its length: water boils at one end (taking in latent heat) and the vapour condenses at the cooler end, releasing energy through black metal fins.

(a)(i) How molecules in the copper conduct energy. [part of 4]

- Heated copper particles vibrate more and pass energy on by collisions; the copper's **free electrons** gain kinetic energy and move through the metal, transferring energy quickly along the pipe.

(a)(ii) How boiling and condensation inside the pipe transfer energy. [part of 4]

- At the hot end the liquid **boils and takes in latent heat**; the vapour travels to the cold end.
- There it **condenses and releases the latent heat**, so energy is carried from the hot end to the cold end (and the liquid flows back).

(a)(iii) Why the heat pipe is able to transfer energy at a fast rate. [part of 4]

A large amount of latent heat is carried by the boiling/condensing fluid, and copper conducts very well, so energy is moved along quickly — much faster than by conduction in a solid copper rod alone.

(c)(i) Experiment to show that black surfaces absorb radiation better than white surfaces. [part of 5]

- Place a black plate and a white plate the **same distance** from a radiant heater (or in the Sun).
- Fix a thermometer (or a coin held by wax) to the back of each. The black plate's thermometer rises faster / its wax melts first, showing black absorbs radiation better. (Keep all else the same — a fair test.)

(c)(ii) Experiment to show that black surfaces emit radiation better than white surfaces at the same temperature. [part of 5]

- Fill a metal cube (a Leslie cube) with hot water so all faces are at the same temperature; one face black, one white.
- Hold a radiation sensor the same distance from each face: the **black face gives the larger reading**, showing it emits radiation better.

Question 21 — Oct/Nov 2006 P2 Q3 (rods over a flame; black vs white teapots)

Copper, brass and glass rods are heated at one end; the other end of each is coated with wax.

(a) How to use the apparatus to find the best conductor. [2]

- Heat all three rods together at one end with the same flame (a fair test — same length, same heating).
- The rod whose wax **melts first** (so the wax marker drops off soonest) is the **best conductor** of heat.

(b) Which teapot (black or white) cools faster, with explanation. [3]

- The **black** teapot cools faster.
- A black (dull) surface is a **better emitter of infra-red radiation** than a white surface.
- So the black teapot radiates energy away more quickly and its water cools sooner.

Question 22 — Oct/Nov 2007 P2 Q4 (solar water heater)

A solar collector with a black base feeds a hot-water tank.

(a) Why the solar collector has a black base. [2]

- A black surface is a **good absorber of infra-red / radiation** from the Sun.
- So it absorbs the maximum energy and heats the water inside as much as possible.

(b) Why the hot water in the collector travels to the hot-water tank. [2]

- The heated water **expands and becomes less dense**, so it rises.
- It rises into the tank while cooler, denser water flows down to take its place — a **convection current** carries the hot water to the tank.

(c)(i) Why it is important to insulate the hot-water tank. [1]

To **reduce energy loss** (by conduction, convection and radiation) so the water stays hot for longer.

(c)(ii) How the hot-water tank is insulated. [1]

Surround it with a thick layer of insulating material that **traps air** (e.g. lagging / foam jacket), since trapped air is a poor conductor and cannot convect.

Question 23 — Oct/Nov 2007 P2 Q5 (atoms in a solid block)

Fig. 5.1 shows atoms in a solid block; end X is heated and energy is conducted to end Y.

(a)(i) How heat is conducted from X to Y by the atoms. [2]

- Heated atoms at X **vibrate more vigorously (greater amplitude / kinetic energy)**.
- They collide with neighbouring atoms and pass on this energy, so the vibration is handed on atom-to-atom along the block until end Y becomes warm.

(a)(ii) Why the solid block expands when it is heated. [1]

As the atoms vibrate more, they push each other slightly further apart, so the **average spacing between atoms increases** and the block expands.

Question 24 — Oct/Nov 2009 P2 Q9 (electric boiler: steel surface vs plastic handle)

A steel boiler with an immersion heater in the water at the bottom has two large plastic handles.

(b)(i) How the heater at the bottom ensures heat is transferred throughout the water. [4]

- Water at the bottom is heated by the immersion heater, so it **expands, becomes less dense and rises**.
- Cooler, denser water from above **sinks** to take its place and is heated in turn.
- This sets up a continuous **convection current** that circulates the water.
- Heating from the bottom (not the top) lets the warm water rise through the cold water, so the convection current reaches all of the water and heats it evenly.

(b)(ii) Why the steel surface at X is hot while the plastic handle at Y is cool. [2]

- **Steel is a good conductor**, so it conducts heat from the hot water to the surface at X, which becomes hot.
- **Plastic is a poor conductor (insulator)**, so very little heat is conducted to handle Y, which stays cool.

Question 25 — Oct/Nov 2010 P22 Q3 (firefighter: shiny jacket & mesh T-shirt)

A firefighter's jacket has a shiny silver outer surface; underneath he wears a loosely-woven mesh T-shirt (string vest).

(b) How the shiny jacket and mesh T-shirt help to keep him cool near intense heat. [4]

- The **shiny silver surface reflects** the infra-red radiation from the fire (a poor absorber), so little radiation is absorbed by the firefighter.
- It is also a poor emitter, but the key point here is reflection of incoming radiant heat.
- The **mesh T-shirt traps a layer of air** between the body and the jacket; trapped air is a **poor conductor**, reducing conduction of heat to the body.
- The loose weave also lets sweat **evaporate** and warm air circulate away from the skin, helping to cool the firefighter.

Question 26 — Oct/Nov 2012 P21 Q10 (heater in a room; insulation)

A heater stands on the floor next to a wall (Fig. 10.2).

(c) Describe and explain how thermal energy is transferred throughout the room. [5]

- Air next to the heater is warmed, so it **expands, becomes less dense and rises**.
- The warm air spreads across the ceiling and cools, becoming denser, and **sinks** on the far side of the room.
- It travels back along the floor to the heater, setting up a circulating **convection current** that warms the whole room.
- The hot heater surface also **radiates infra-red radiation** directly to nearby objects and people.
- (Conduction through air is slow, so convection and radiation do most of the heating.)

(d) One method of thermal insulation used to keep a room warm, and why it works. [3]

- Method: **loft / cavity-wall insulation** (e.g. fibreglass or foam) — or double glazing.
- It **traps a layer of air**; trapped air is a poor conductor, so it reduces conduction of heat out of the room.
- Because the air is trapped it cannot circulate, so it also reduces convection — less energy escapes and the room stays warm.

Question 27 — Oct/Nov 2012 P22 Q5 (Sun to Earth; white houses)

(a) Why no heat is transferred from the Sun to the Earth by conduction or convection. [2]

- Conduction and convection both need **particles / a material medium** to carry the energy.
- Space between the Sun and the Earth is a **vacuum (no particles)**, so neither process can take place there — energy travels only by radiation.

(b) How painting houses white keeps a comfortable temperature in a sunny/hot day and cold night. [3]

- **During the day:** a white surface is a **poor absorber and good reflector** of radiation, so it reflects much of the Sun's radiation and the house stays cooler.
- **During the night:** a white surface is also a **poor emitter** of radiation, so the house radiates away less of its stored heat and stays warmer (does not get as cold).

Question 28 — Oct/Nov 2013 P21 Q4 (food cooked under an electric grill)

Red-hot heating elements above the food transmit thermal energy to it by radiation.

(a) What is meant, in this case, by radiation. [2]

- Radiation is the transfer of energy by **infra-red (electromagnetic) waves**.
- It needs **no medium / can travel through a vacuum (or air)**; the energy travels in straight lines from the hot element to the food.

(b)(i) Why very little thermal energy reaches the food by conduction. [1]

The air between the element and the food is a poor conductor, so almost no energy is conducted across the gap.

(b)(ii) Why very little thermal energy reaches the food by convection. [1]

The hot elements are above the food, so warm air rises away from the food (upwards); convection currents carry heat upward, not down to the food.

Question 29 — Oct/Nov 2014 P21 Q10 (white plastic electric kettle)

An electric kettle has a white plastic casing and the heating element in the base.

(a)(i) How thermal energy is transferred throughout the water. [3]

- Water at the bottom is heated, so it **expands, becomes less dense and rises**.
- Cooler, denser water **sinks** to replace it and is heated in turn.
- This forms a circulating **convection current** that transfers energy throughout the water.

(a)(ii) Why a kettle with its element at the top does not heat the water uniformly. [1]

Warm water at the top is already less dense, so it cannot rise / no convection current is set up; the cold water below stays cold (and water is a poor conductor), so the water is not heated uniformly.

(c)(i) One advantage of using plastic for the casing. [1]

Plastic is a poor conductor (good insulator), so the outside stays cool and safe to touch / less heat is lost.

(c)(ii) One advantage of choosing white for the outside of the casing. [1]

A white surface is a poor emitter of radiation, so less energy is radiated away and the water stays hot longer.

Question 30 — Oct/Nov 2015 P22 Q4 (copper saucepan, wooden handle)

A copper saucepan with a wooden handle of cold water sits on a red-hot heating element.

(a) Why wood is a suitable material for the handle. [1]

Wood is a poor conductor (good insulator) of heat, so the handle stays cool enough to hold safely.

(b)(i) In terms of free electrons, how heat is transferred through the copper base. [3]

- Copper has many **free (delocalised) electrons**.
- At the hot base they gain kinetic energy and move faster.
- They move through the metal and collide with particles/electrons at the cooler side, transferring energy quickly (plus particle vibration), so the base conducts heat well.

(b)(ii) How heat is transferred upwards through the water. [3]

- Water at the bottom is heated, so it **expands and becomes less dense**.
- It **rises**, while cooler, denser water sinks to take its place.
- This sets up a **convection current** that carries energy upwards and throughout the water.

Question 31 — Oct/Nov 2016 P21 Q10 (pan of oil on a hotplate)

A metal pan of oil with a handle stands on an electric hotplate.

(b)(ii)(1) How thermal energy is conducted through the metal base (free electrons/molecules). [3]

- The hot base makes the metal particles **vibrate more** and pass energy on by collisions.
- The metal's **free electrons** gain kinetic energy and move through the metal.
- They collide with cooler particles/electrons higher up, transferring energy quickly through the base.

(b)(ii)(2) How thermal energy spreads to all the oil in the pan. [3]

- Oil at the bottom is heated, expands, becomes less dense and rises.
- Cooler, denser oil sinks to take its place and is heated in turn.
- This circulating **convection current** spreads energy to all the oil.

(b)(ii)(3) Suitable material for the handle, with reason. [1]

A plastic or wooden handle — these are poor conductors (insulators), so the handle stays cool and is safe to hold.

Question 32 — Oct/Nov 2017 P22 Q10 (steel boiler, heater at the bottom)

An electric heater sits at the bottom of the water in a steel boiler.

(c)(i) How thermal energy is transferred from the heater throughout the water. [3]

- Water heated at the bottom **expands, becomes less dense and rises**.
- Cooler, denser water sinks to replace it and is heated in turn.
- A circulating **convection current** carries energy throughout the water.

(c)(ii) In terms of particles, how thermal energy passes through the steel. [3]

- Heated steel particles **vibrate more vigorously** and pass energy to neighbours by collisions.
- The steel's **free electrons** gain kinetic energy, move through the metal and collide with cooler particles.
- So energy is conducted from the hot inner surface to the outer surface.

(c)(iii) What happens to the density of the steel as its temperature increases (in terms of particles). [2]

- As the steel is heated its particles vibrate more and move slightly further apart, so the steel **expands (volume increases)** while its mass stays the same.
- Since density = mass ÷ volume, the **density decreases**.

Question 33 — Oct/Nov 2018 P22 Q3 (copper kettle, expansion)

A cylindrical copper kettle of cold water has an electric heater at the base; the water level is X.

(a) State and explain the advantage of heating the water from below. [2]

- Heating from below lets the warm water (less dense) rise and cold water sink, setting up a **convection current**.
- So energy is carried throughout the water and **all the water is heated** (heated quickly and evenly).

(b)(i) In terms of molecules, why water expands when heated. [2]

- The water molecules gain kinetic energy and **move faster / vibrate more**.
- So they move slightly further apart on average (occupy more space), and the water expands.

(b)(ii) What happens to level X (copper and water both expand). [1]

Level X rises: water expands much more than copper for the same temperature rise, so the water level in the kettle goes up.

Question 34 — Oct/Nov 2018 P22 Q4 (solar panels, black surface)

Black solar panels on a roof use the Sun's energy to generate electricity and heat water.

(a)(i) How energy from the Sun travels through space to the Earth. [1]

By radiation (infra-red / electromagnetic radiation, through the vacuum of space).

(a)(ii) Advantage of using panels with a black surface. [2]

- A black surface is a **good absorber of radiation**.
- So it absorbs the maximum amount of the Sun's energy, heating the water (and generating electricity) more effectively.

Question 35 — Oct/Nov 2019 P21 Q9 (water cooler)

A water cooler has a room-temperature reservoir above a tank of cold water; a refrigeration unit pumps cold liquid through a copper pipe in the tank.

(a) Why the room-temperature water in the reservoir does not mix with the cold water in the tank below. [2]

- Cold water is **denser** than the warmer water, so it stays at the bottom.
- The less-dense warm water stays on top; there is **no convection current** to mix them (warm above cold is a stable arrangement), so they do not mix.

(b)(i) Why the pipe is made from copper. [1]

Copper is a very good conductor of heat, so thermal energy passes quickly from the water into the cold liquid in the pipe.

(b)(ii) In terms of free electrons, how thermal energy is transferred through the copper. [3]

- Copper contains many **free (delocalised) electrons**.
- Where it is warmer they gain kinetic energy and move faster, travelling through the metal.
- They collide with cooler particles/electrons, transferring energy quickly from the warm outside of the pipe to the cold liquid inside.

(b)(iii) How the cooled water near the copper pipe mixes with the rest of the water in the tank. [3]

- Water near the pipe is cooled, so it **contracts, becomes more dense and sinks**.
- Warmer, less-dense water rises to take its place and is cooled in turn.
- This sets up a **convection current** that mixes and cools all the water in the tank.

Question 36 — Oct/Nov 2019 P22 Q3 (black solar panels; energy from the Sun)

Solar panels are used to heat water; the energy comes from the Sun.

(a)(i) How the energy is produced inside the Sun. [2]

- By **nuclear fusion**: hydrogen nuclei join together to form helium nuclei.
- A small loss of mass is released as a very large amount of energy.

(a)(ii) How this energy is transferred to Earth. [1]

By radiation (infra-red / electromagnetic radiation through the vacuum of space).

(b) Why solar panels are usually black. [2]

- A black surface is a **good absorber of (infra-red) radiation**.
- So the panel absorbs the maximum energy from the Sun, heating the water as much as possible.

Question 37 — Oct/Nov 2020 P22 Q3 (hot-water tank with two heaters)

A hot-water tank has two heaters: X higher up, Y near the bottom. The tank is full of cold water and X is switched on; the water above X heats quickly but the water below X heats much more slowly.

(a)(i) The process that causes the water above X to increase in temperature. [3]

- Water heated by X **expands, becomes less dense and rises**.
- Cooler, denser water above sinks and is heated in turn.
- This **convection current** circulates through the water above X, so all of it is heated quickly.

(a)(ii) Why the water below X heats much more slowly (Y switched off). [2]

- Warm water rises, so it cannot move down to the water below X; **no convection current is set up below X**.
- Water is a **poor conductor**, so very little energy is conducted downwards — hence the water below X heats only slowly.

(b) Why a plastic with many small pockets of trapped air is a good insulator. [2]

- The plastic and the **trapped air are both poor conductors**, so little heat is conducted through.
- Because the air is trapped in small pockets it **cannot circulate**, so it cannot carry energy away by convection either — so very little energy escapes.

Question 38 — Oct/Nov 2021 P21 Q3 (Sun's energy; radiation to Earth)

A nuclear reaction at the centre of the Sun releases thermal energy, which is emitted from the surface into space by radiation.

(a) Name of the type of nuclear reaction at the centre of the Sun. [1]

Nuclear **fusion**.

(b)(i) Describe the radiation emitted from the surface of the Sun. [2]

- It is **electromagnetic radiation** (mainly infra-red, visible light and ultraviolet); a transverse wave.
- It can travel through a **vacuum** and needs no medium.

(b)(ii) State the speed of this radiation in a vacuum. [1]

speed = **3.0×10^8 m/s**.

(b)(iii) Time for the radiation to travel to Earth, 1.5×10^{11} m away. [2]

time = distance ÷ speed = $(1.5 \times 10^{11}) \div (3.0 \times 10^8)$.

time = $0.5 \times 10^3 = 500$ s.

Final: time = **500 s (about 8.3 minutes)**.

(c) One advantage of wearing white clothes on sunny days. [2]

- White is a **poor absorber and good reflector of radiation**.
- So white clothes reflect much of the Sun's radiation and absorb less heat, keeping the wearer cooler.

Note from Megalecture. These are original Megalecture worked solutions prepared for revision use. Several items recur across the years (Sun-to-Earth radiation, convection currents in heated water, good/poor emitters and absorbers); they are answered consistently above. Where the topical compilation reproduces only part of a longer exam question, only that part is solved here. Please verify against your own marking before classroom use.