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IGCSE PHYSICS 0625 · TOPICAL PAST PAPERS

Thermal Properties of Matter — Paper 2

Worked Solutions (Theory / Structured) — Part 2 of 2

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Thermal Properties of Matter — Paper 2 · Worked Solutions (Part 2)

Megalecture worked solutions — model answers with working; please verify before classroom use. (Part 2 of 2.) These cover the second half of the topical structured-question compilation (**Q28(b) onward through Q55**). Questions are numbered as printed in the source paper, continuing from Part 1. Final numerical answers are shown in **bold** with units; use *g* as stated in each part.

Worked Solutions — Q28 to Q55

Question 28(b) *5054/21/M/J/20*

A full glass flask of water is heated from below; the liquid level X first falls for a few seconds, then rises.

(i) The flask is heated first, so the **glass expands before the heat reaches the water**. The flask becomes slightly larger in volume, so the water has more room and its level **falls**. Shortly after, the heat conducts through to the water; water expands much more than glass for the same temperature rise, so the level then **rises**.

Question 29 *5054/21/M/J/20*

Steel rod, m = 2.0 kg, c = 460 J/(kg °C), cooled from 500 °C to 50 °C.

(a) Heat lost $Q = m\ c\ \Delta\theta = 2.0 \times 460 \times (500 - 50) = 2.0 \times 460 \times 450$ = **414 000 J (4.14 × 10^5 J)**.

(b)(i) One way boiling differs from evaporation: **boiling occurs only at a fixed temperature (the boiling point) and throughout the liquid (bubbles form within it), whereas evaporation happens at any temperature and only at the liquid surface.**

(b)(ii) As the water cools, the molecules move more slowly (have less kinetic energy). Fewer molecules now have enough energy to escape from the surface, so the **rate of evaporation decreases**.

Question 30 *5054/21/M/J/22*

(a) *Latent heat of fusion*: the **thermal energy needed to change a substance from solid to liquid (to melt it) at its melting point, without any change in temperature.**

(b)(i) Graph for metal P (100 °C → 400 °C, melting point 250 °C): a line rising steadily from 100 °C up to 250 °C, then a **horizontal flat section at 250 °C** (while it melts), then rising again from 250 °C up to 400 °C.

(b)(ii) Q has a greater latent heat of fusion but the same melting point and heat capacity, with the same power supplied. So the sloping parts of the graph are the **same gradient as for P**, but the **horizontal (melting) section at 250 °C is longer** for Q, because more energy (and so more time at constant power) is needed to melt it.

Question 31 *5054/22/M/J/21*

Energy conversion in a mobile phone powered by a battery.

(a)(i) Energy stored in the battery: **chemical energy**.

(a)(ii) Useful output from the battery: **electrical energy**.

(a)(iii) Two useful outputs from the phone: **light (from the screen) and sound** (also acceptable: electromagnetic/radio waves).

(b) Charge $Q = I\,t = 1.3 \times 10^{-3}\ A \times (2.0 \times 60)\ s = 1.3 \times 10^{-3} \times 120$ = **0.156 C**.

(c)(i) Thermal energy $Q = m\,c\,\Delta\theta = 0.110\ kg \times 830 \times 5.0$ = **456.5 J (≈ 460 J)**.

(c)(ii) *Efficiency* = **(useful energy output ÷ total energy input) × 100%** — the fraction of the input energy that is transferred usefully.

(c)(iii) Total input = useful (5200 J) + wasted heat (456.5 J) = 5656.5 J. Efficiency $= 5200 \div 5656.5 \times 100\%$ = **92% (0.92)**.

(c)(iv) The calculated value is too high because **not all the wasted energy was counted**: some thermal energy escapes/is conducted away from the battery to the surroundings, so the true heat produced is more than the 456.5 J found from the 5.0 °C rise. Counting less waste makes the efficiency look larger than it really is.

Question 32 *5054/22/M/J/22*

Sealed cardboard tube, metal pieces total mass 150 g, turned over so pieces fall a vertical distance 1.2 m each turn. g = 10 N/kg.

(a) The gravitational PE of the falling pieces is transferred to **kinetic energy and then to thermal (internal) energy** (of the metal pieces, as they hit and rub).

(b)(i) Loss in GPE per turn $= m\,g\,h = 0.150 \times 10 \times 1.2$ = **1.8 J**.

(b)(ii) 80 turns $\rightarrow$ total energy to the metal = 80 × 1.8 = 144 J, raising the metal (0.150 kg) by 7.0 °C. $c = Q \div (m\,\Delta\theta) = 144 \div (0.150 \times 7.0) = 144 \div 1.05$ = **137 J/(kg °C)**.

(b)(iii) Doing the experiment more quickly means **less time for thermal energy to be lost to the surroundings** (tube and air), so a larger share of the energy stays in the metal and a greater temperature rise is obtained.

Question 33 *5054/02/O/N/03*

A refrigerator: liquid boils in the ice-box taking in latent heat; gas condenses at the back.

(a)(i) Similarity: in both boiling and evaporation a liquid changes to a gas (vapour). **Difference:** boiling happens at one fixed temperature throughout the liquid, while evaporation happens at any temperature and only at the surface.

(a)(ii) To boil the liquid, energy (latent heat) must be supplied to **do work against the forces of attraction between the molecules**, pulling them far apart so they become a gas; this energy increases their potential energy without raising the temperature.

Question 35 *5054/02/O/N/07*

Geothermal source: 1000 kg cold water at 20 °C pumped down; returns as 100 kg steam and 900 kg water at 100 °C. c_{water} = 4200 J/(kg °C).

(a)(i) Renewable energy source shown: **geothermal energy** (energy from hot rocks underground).

(a)(ii) A *renewable* source is one that **will not run out / is continually replaced** (it is naturally replenished and not used up).

(b)(i) Energy to heat 1000 kg of water from 20 °C to 100 °C: $Q = m\ c\ \Delta\theta = 1000 \times 4200 \times 80$ = **3.36×10^8 J (336 MJ)**.

Question 36 *5054/02/O/N/08*

Waterfall: water at 7.2 °C falls 700 m. g = 10 N/kg, c = 4200 J/(kg °C).

(a) Change in GPE per kg $= m\ g\ h = 1 \times 10 \times 700$ = **7000 J**.

(b) All 7000 J per kg becomes heat: $\Delta\theta = Q \div (m\ c) = 7000 \div (1 \times 4200) = 1.67\ °C$. Final temperature = 7.2 + 1.67 = **8.9 °C (8.87 °C)**.

Question 37 *5054/02/O/N/09*

Boiler holds 35 kg of water at 22 °C; c_{water} = 4200 J/(kg °C); 2600 W immersion heater.

(a)(i) Heat to raise water from 22 °C to its boiling point (100 °C, Δθ = 78 °C): $Q = m\ c\ \Delta\theta = 35 \times 4200 \times 78$ = **1.1466×10^7 J (≈ 1.15×10^7 J)**.

(a)(ii) Minimum time $t = Q \div P = 1.1466 \times 10^7 \div 2600$ = **4410 s (≈ 73 min)**.

(a)(iii) The actual time is longer because **some thermal energy is lost to the surroundings** (the boiler walls and air), so not all the heater's energy goes into the water.

(b)(i) The heater X is at the bottom: water heated there expands, becomes less dense and rises, while cooler denser water sinks to take its place. These **convection currents circulate and heat all the water**. If placed at the top, the warm water would simply stay at the top (no convection downwards), so the water below would heat only slowly by conduction.

(b)(ii) Steel handle Y conducts heat away from the boiler and would become hot; the plastic handle X is a **poor conductor (good insulator) of heat**, so it stays cool and is safe to touch.

(c)(i) The process that produces water vapour from the surface (below boiling point): **evaporation**.

(c)(ii) Two differences: evaporation occurs **at any temperature** (boiling only at the boiling point); evaporation occurs **only at the surface** (boiling occurs throughout the liquid with bubbles).

Question 38 *5054/21/O/N/12*

Heater of 16 bricks, each 7.5 kg; heated 17 °C → 96 °C; c = 2300 J/(kg °C).

(a) Total mass = 16 × 7.5 = 120 kg; Δθ = 96 − 17 = 79 °C. $Q = m\ c\ \Delta\theta = 120 \times 2300 \times 79$ = **2.18×10^7 J (21 800 000 J)**.

(b)(i) The same energy is released over 7.0 hours = 25 200 s. $\text{rate} = Q \div t = 2.18 \times 10^7 \div 25\ 200$ = **865 W (J/s)**.

(b)(ii) At the start of the day the bricks are hottest, so the **temperature difference between the bricks and the room is largest**; heat is lost faster when this difference is greater, so the rate of energy release is higher early on.

Question 39 *5054/21/O/N/13*

Swimming pool: 450 m³ of water at 12 °C; ρ = 1000 kg/m³; c = 4.2 J/(g °C) = 4200 J/(kg °C).

(a) Mass $= \rho\ V = 1000 \times 450$ = **450 000 kg (4.5 × 10^5 kg)**.

(b)(i) Δθ = 27 − 12 = 15 °C. $Q = m\ c\ \Delta\theta = 450\ 000 \times 4200 \times 15$ = **2.835 × 10^{10} J**.

(b)(ii) The heating system must supply **more** energy than this because **some heat is lost to the surroundings** (to the air, the pool walls and by evaporation), so not all of it goes into raising the water's temperature.

Question 40 *5054/22/O/N/13*

Molten wax cools in a cool room; T–time graph has a flat section from 3 to 16 minutes at about 56 °C.

(a) Melting point = temperature of the horizontal part of the graph = **56 °C**.

(c)(i) Between 3 and 16 minutes the wax is **freezing / solidifying** (changing from liquid to solid at its freezing point).

(c)(ii) As the wax solidifies, the molecules form bonds and **release latent heat**. This energy released exactly replaces the energy lost to the room, so the average kinetic energy of the molecules (and hence the temperature) **stays constant** until all the wax has solidified.

Question 41 *5054/21/O/N/14*

Electric kettle: 230 V supply, on for 3.5 min, current 9.6 A; 1.6 kg water at 22 °C; c = 4200 J/(kg °C).

(b)(i) t = 3.5 × 60 = 210 s. Thermal energy $= V\ I\ t = 230 \times 9.6 \times 210$ = **463 680 J (≈ 4.64 × 10^5 J)**.

(b)(ii) Maximum rise assumes all this energy heats the water: $\Delta\theta = Q \div (m\ c) = 463\ 680 \div (1.6 \times 4200) = 69\ °C$. Maximum temperature = 22 + 69 = **91 °C**.

(b)(iii) The real temperature is lower because **some thermal energy is lost to the surroundings** (heating the kettle body and lost to the air), so less energy actually goes into the water.

(d)(i) *Boiling point*: the **temperature at which a liquid boils — it changes to a gas throughout the liquid (at a given pressure).**

(d)(ii) While the water boils, the supplied thermal energy is used as **latent heat of vaporisation**: it does work separating the molecules against their attractive forces (turning liquid into gas) rather than raising the temperature, so the temperature stays at the boiling point.

Question 42 *5054/22/O/N/14*

Liquid wax at 90 °C (t = 0), melting point 58 °C, cools to room temperature 23 °C.

(a) Sketch: temperature starts at 90 °C, falls steadily to 58 °C, then a **horizontal flat section at 58 °C** (while it solidifies), then falls again, levelling off towards 23 °C. Mark 90, 58 and 23 °C on the temperature axis.

(b) Point H (half solid, half liquid) lies on the **middle of the horizontal section at 58 °C** — halfway along the flat part of the curve.

Question 43 *5054/21/O/N/15*

Steam cleaner: water heated to its boiling point and turned to steam.

(a) *Boiling point*: the **temperature at which a liquid turns into a gas throughout its volume (at the stated pressure)**.

(b)(i) Molecular structure of a liquid: the molecules are **close together but not in a fixed regular pattern**; they are arranged randomly and can **move/slide past one another**, so a liquid has a fixed volume but no fixed shape.

(b)(ii) Energy must be supplied as the water boils because it is used to **do work against the attractive forces between the molecules**, pulling them far apart to form a gas (latent heat of vaporisation); it increases their potential energy, not the temperature.

Question 44 *5054/21/O/N/16*

Cooking oil: 680 g, ρ = 0.85 g/cm³, c = 2.0 J/(g °C), heated 20 °C → boiling point 260 °C.

(b)(i) Volume $= m \div \rho = 680 \div 0.85$ = **800 cm³**.

(c)(i) *Boiling point*: the **temperature at which the liquid boils — turns to gas throughout the liquid (at the given pressure)**.

(c)(ii) Δθ = 260 − 20 = 240 °C. $Q = m\ c\ \Delta\theta = 680 \times 2.0 \times 240$ = **326 400 J (≈ 3.26 × 10^5 J)**.

(c)(iii) The hotplate's energy output is larger because **some thermal energy is lost to the surroundings** (to the pan and the air), so not all of it is transferred to the oil.

Question 45 *5054/22/O/N/16*

Kettle on a gas burner; water reaches 100 °C at t = 250 s; 1.5 kg water, c = 4200 J/(kg °C). From Fig. 4.2 the water starts at about 24 °C.

(a) *Boiling point*: the **temperature at which water turns into steam throughout the liquid (100 °C at normal pressure)**.

(b)(i) Rise read from the graph ≈ 100 − 24 = 76 °C. $\text{Increase in internal energy} = m\ c\ \Delta\theta = 1.5 \times 4200 \times 76$ = **4.79 × 10^5 J** (≈ 4.7–4.8 × 10^5 J depending on the start value read).

(b)(ii) Heat is supplied at a constant rate, but as the water gets hotter the **temperature difference between the water and the surroundings increases, so heat is lost to the surroundings more quickly**. Less of the supplied energy is left to raise the temperature, so the temperature rises more slowly (the graph flattens).

(c)(i) While boiling, the temperature of the water **stays constant at 100 °C**.

(c)(ii) Energy is still needed because it is used as **latent heat of vaporisation** — to do work against the attractive forces and separate the molecules far apart into a gas — rather than to increase their kinetic energy, so the temperature does not rise.

Question 46 *5054/21/O/N/17*

Gold (melting point 1100 °C) melted in a furnace; 0.84 kg of solid gold at its melting point then melts.

(b)(i) Thermal energy is needed to melt the gold to **do work against the forces of attraction between the molecules**, allowing them to break out of their fixed lattice positions and move around (solid → liquid). This energy (latent heat of fusion) increases the molecules' potential energy, so the temperature stays at 1100 °C while it melts.

Question 47 *5054/22/O/N/17*

Boiler plugged into 230 V mains, operating at 2.8 kW; water heated 23 °C → 75 °C, with one part 49 °C → 75 °C; c_{water} = 4200 J/(kg °C).

(a)(i) Current $I = P \div V = 2800 \div 230$ = **12.2 A**.

(a)(ii) A suitable fuse is the next standard value above the working current: **13 A**.

(b)(i) For 1 kg of water heated 49 °C → 75 °C (Δθ = 26 °C): $\text{change in internal energy} = m\ c\ \Delta\theta = 1 \times 4200 \times 26$ = **1.09×10^5 J (109 200 J per kg)**.

(b)(ii) It takes longer to raise the temperature from 49 °C to 75 °C than from 65 °C to 75 °C because a **larger temperature change requires more thermal energy** (Q = m c Δθ), and at constant power more energy means more time.

(c)(iii) As the steel gets hotter its particles **vibrate more and move slightly further apart, so the steel expands**. Its mass stays the same but its volume increases, so its **density decreases** (density = mass ÷ volume).

Question 48 *5054/21/O/N/18*

Mercury-in-glass clinical thermometer with a constriction.

(c) When the temperature rises, the mercury molecules **gain kinetic energy and move/vibrate faster**, so they move slightly further apart on average. The mercury therefore **expands** and is pushed further up the narrow capillary tube past the scale, giving a higher reading. (The constriction stops it running back when removed from the patient.)

Question 49 *5054/22/O/N/18*

Cylindrical copper kettle of cold water, level X marked; both water and copper expand on heating.

(b)(i) When water is heated its molecules **gain energy and vibrate/move faster**, so they move slightly further apart on average. The same mass now occupies a larger volume, so the water **expands**.

(b)(ii) The water level **rises (X goes up)**. Both the copper and the water expand, but for the same temperature rise **water expands much more than copper**, so the water expands past the (smaller) expansion of the container and the level rises.

Question 50 *5054/22/O/N/18*

Solar panels on a roof; 51 kg of water pumped through, heated 16 °C → 45 °C; supply 24 V; c = 4200 J/(kg °C).

(a)(i) Energy from the Sun reaching the Earth travels as **electromagnetic waves / radiation** (no medium needed — it crosses the vacuum of space).

(a)(ii) A black surface is the **best absorber of (infra-red) radiation**, so it absorbs the Sun's energy most efficiently and heats the water faster.

(b)(i) In 1 hour (3600 s) at a current that delivers power P = V I: electrical energy = P × t. Using charge through the panel, electrical energy $= V\ I\ t$; with the data given (e.g. I from the circuit) $E = V\ I\ t$. **E = V × I × 3600 J** (substitute the stated current).

(b)(ii) Δθ = 45 − 16 = 29 °C. $\text{thermal energy increase} = m\ c\ \Delta\theta = 51 \times 4200 \times 29$ = **6.21×10^6 J (6 211 800 J)**.

Question 51 *5054/21/O/N/19*

Office water cooler: 250 g of water cooled from 21 °C to 7 °C; c = 4200 J/(kg °C).

(c) m = 250 g = 0.25 kg; Δθ = 21 − 7 = 14 °C. $Q = m\,c\,\Delta\theta = 0.25 \times 4200 \times 14$ = **14 700 J (≈ 1.47×10^4 J)**.

Question 52 *5054/22/O/N/19*

Salt produced by trapping sea water in shallow ponds and letting it evaporate.

(a) Two ways evaporation differs from boiling: (1) evaporation occurs **at any temperature** (boiling only at the boiling point); (2) evaporation occurs **only at the surface** of the liquid (boiling occurs throughout the liquid, forming bubbles).

(b) During evaporation, the **faster-moving (higher-energy) molecules near the surface escape from the liquid** into the air. This leaves behind the slower molecules, so the water gradually turns to vapour (and the salt is left behind).

(c)(i) Large surface area is used because **a bigger surface lets more molecules escape per second, so evaporation is faster**.

(c)(ii) In a cold country the method works poorly because **at lower temperatures the molecules have less energy, so fewer escape and evaporation is much slower** (also there is usually less sunshine to warm the water).

Question 53 *5054/22/O/N/19*

Boiling liquid trapped in a cylinder by a piston; an electric heater turns the boiling liquid to gas.

(a) *Boiling point*: the **temperature at which a liquid boils — it turns into a gas throughout the whole liquid (at the given pressure)**.

(b) Energy must be supplied to **do work against the attractive forces between the molecules**, separating them so they are far apart and free to move as a gas (latent heat of vaporisation). The energy increases their potential energy, not their kinetic energy, so the temperature stays at the boiling point.

(c) To find the power, connect an **ammeter in series** with the heater (to measure the current) and a **voltmeter in parallel** across the heater (to measure the p.d.); power = V × I.

(e) The upward force on the piston **does not change**. The piston moves at constant speed, so it is in equilibrium: the gas pressure stays constant (it is the saturated vapour at the boiling point) and the piston area is constant, so the upward force (pressure × area) balances the constant weight of the piston and stays the same throughout.

Question 54 *5054/22/O/N/19*

Oil in a glass cylinder cooling in a freezer at −18 °C; takes 700 s to cool 20 → 10 °C but 1900 s to cool 0 → −10 °C; a flat section appears at the freezing point.

(a) The two times are different because **as the oil cools, the temperature difference between the oil and the freezer gets smaller, so heat is lost more slowly**. Cooling from 0 to −10 °C is closer to the freezer temperature, so it loses energy at a slower rate and takes longer. (The oil may also be solid by then, with a different specific heat capacity.)

(b) As the oil cools from 20 °C to 0 °C its molecules **lose energy and move/vibrate more slowly**, so they move slightly closer together. The oil **contracts**, so the level of the oil in the cylinder **falls**.

(c)(i) Melting point = freezing point = temperature of the horizontal part of the graph = **−10 °C**.

(c)(ii) Between t = 3600 s and 10 800 s the oil is **solidifying**. As bonds form between molecules, **latent heat is released**, which replaces the energy lost to the freezer, so the average kinetic energy (and thus the temperature) stays constant until all the oil has frozen.

(e) The graph is steeper before the flat section (liquid) than after it (solid). Both states lose energy to the freezer at a similar rate, but a steeper fall means a faster temperature change for the same energy loss. So the **liquid oil has the smaller specific heat capacity** and the **solid oil has the larger specific heat capacity** (more energy is needed per °C in the solid, so its temperature falls more slowly — the shallower part).

Question 55 *5054/22/O/N/20*

Hot horseshoe dropped into 8.0 kg of water at 18 °C; final temperature 43 °C; c_{water} = 4200 J/(kg °C); heat capacity of horseshoe = 850 J/°C.

(b)(i) Δθ = 43 − 18 = 25 °C. $\text{Energy to water} = m\ c\ \Delta\theta = 8.0 \times 4200 \times 25$ = **840 000 J (8.4×10^5 J)**.

(b)(ii) The horseshoe loses this 840 000 J cooling from its starting temperature to 43 °C. Using heat capacity C = 850 J/°C: $Q = C \times (T - 43) \rightarrow T - 43 = 840\ 000 \div 850 = 988\ °C$; T = 988 + 43 = **1031 °C (≈ 1030 °C)**.

Note from Megalecture. These are original Megalecture worked solutions prepared for revision use; descriptive (explain/state) answers are model responses, so wording may differ from the official mark scheme. Where a graph value had to be read (e.g. Q45, Q40, Q54), small differences in the read-off are acceptable. Please verify before classroom use. (Part 2 of 2.)