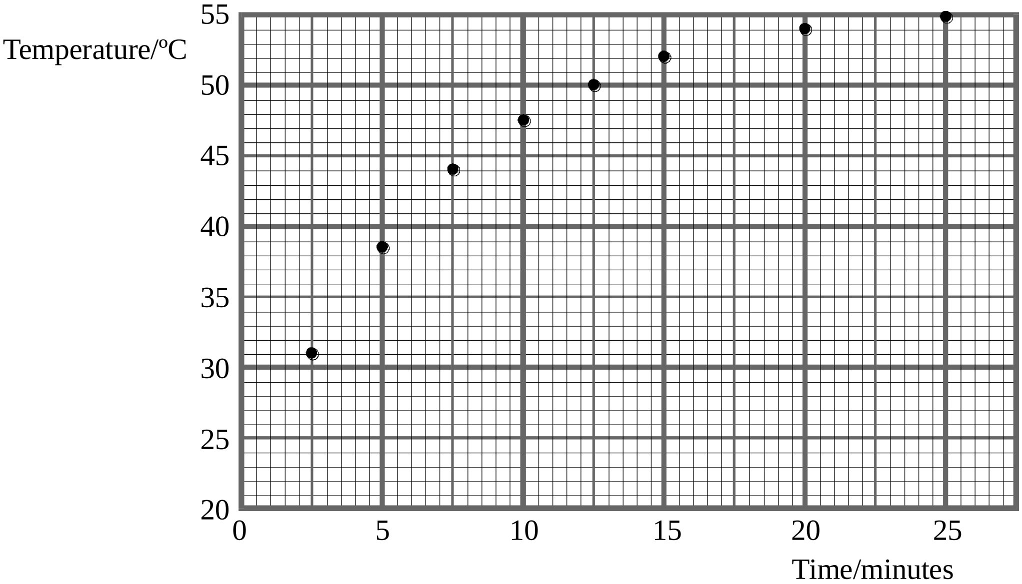
HEAT ENERGY ANSWERS

1. A student pours 500 g of water into an aluminium saucepan of mass 1.20 kg, heats it over a steady flame and records the temperature as it heats up. the temperatures are plotted as shown below.



Calculate the total heat capacity of the saucepan and water.

Specific heat capacity of water = 4200 J kg^{-1} K^{-1}
Specific heat capacity of aluminium = 900 J kg^{-1} K^{-1}

Heat capacity = (0.500 kg × 4200 J kg^{-1} K^{-1}) + (1.20 kg × 900 J kg^{-1} K^{-1}) (1) + (1)

Heat capacity = 3180 J K^{-1} (1)

(3 marks)

Find the rate of rise of water temperature at the beginning of the heating process.

Rate of rise of water temperature = $\frac{(11K)}{(150s)}$ **(1)**

Rate of rise of temperature = 0.073 K s^{-1} (1)

(2 marks)

Hence find the rate at which energy is supplied to the saucepan and water.

Rate of energy supply = (3180 J K^{-1}) × (0.073 K s^{-1}) (1)

Rate of energy supply = 0.23 kW (1)

(2 marks)

Explain why the rate at which the temperature rise slows down progressively as the heating process continues.

As the temperature of the saucepan increases (1)
an increasing fraction of the heat supplied per second goes to the surroundings (1)

(2 marks)
[Total 9 marks]

2. You are asked to measure the specific heat capacity of aluminium using a cylindrical block of aluminium which has been drilled out to accept an electrical heater.

Draw a complete diagram of the apparatus you would use.

Diagram showing

heater in aluminium block with suitably-placed thermometer, (1)
lagging round the surface of the block and (1)
a circuit-diagram with correctly-placed voltmeter, ammeter and power supply (1)

(3 marks)

Describe how you would carry out the experiment and list the measurements you would take.

Measure and record the mass of the block (m) (1)
and the initial temperature (θ_1) (1)

Switch on the current and start the clock at the same time.

Record voltmeter and ammeter readings (I and V). (1)

Stop clock after an appreciable rise in temperature. Note time (t). (1)

Note final temperature of block (θ_2) (1)

(5 marks)

Explain how you would calculate the specific heat capacity of aluminium from your measurements.

Energy transferred to block = IVt (1)

Increase in internal energy of block = $m\,c\,(\theta_2 - \theta_1)$ (1)

Specific heat capacity of aluminium $c = \dfrac{IVt}{m(\theta_2 - \theta_1)}$ **(1)**

(3 marks)
[Total 11 marks]

3. A container holding 2.3 litres of milk at 15 °C is put into a freezer. Calculate the energy that must be removed from the milk to reduce its temperature to the freezer temperature of –30 °C. Assume that the milk behaves like ice and water.

Specific heat capacity of water = 4.2 kJ kg^{-1} K^{-1}
Specific heat capacity of ice 2.1 kJ kg^{-1} K^{-1}
Specific latent heat (enthalpy) of fusion of ice = 330 kJ kg^{-1}
Density of water = 1.0 kg litre^{-1}

$E = mc_1\,\Delta\theta_1 + mL + mc_2\,\Delta\theta_2$ (1)
m = 2.3 kg
(2.3kg) (4200 Jkg^{-1} K^{-1}) (15K) or 145 kJ (1)
(2.3kg) (330,000 Jkg^{-1}) or 759 kJ(1)
(2.3kg) (2100 Jkg^{-1} K^{-1}) (30K) or 145 kJ (1)

Energy removed = .. 1.05 mJ **(1)**

(6 marks)

It costs 8.2 p per kWh to remove energy from the freezer. What is the cost of freezing the milk?

$$\frac{(8.2\text{p/kWhr})}{1000\times 3600\text{J/kWhr}}\times(1.05\times 10^{6}\,\text{J})\ \textbf{(1)}$$

Cost = 2.4p (1)..

(2 marks)
[Total 8 marks]

4. Energy given out = $mc\Delta\theta$ **(1)**
= (1.2 × 1000 kg) (4200 J kg^{-1} K^{-1}) (98 ^{o}C – 65 ^{o}C) **(1)**
Energy = 166 MJ **(1)** **3**

Time = $\dfrac{\text{Energy}}{\text{Power}} = \dfrac{W}{P}$ **(1)**

= $\dfrac{1.66\times 10^{8}\text{ J}}{6\times(1.5\times 10^{3}\text{ W})}$ **(1)**

Time = 18 400 s/307 min/5.1 h **(1)** **3**
[Do not penalise modest rounding differences]

Any two of the following:
Temperature difference greater in morning than evening **(1)**
Clear reasons **(1)**
∴ greater output in morning than evening **(1)** **2**
[Total 8 marks]

5. Initial rate of rise of water temperature:

[Allow (1) for attempt to find gradient of graph at origin.]

Rate of temperature rise = temperature rise/corresponding time interval

=(0.030→0.042)Ks^{-1} [Allow °Cs^{-1}] 2

[Note: (1.8→K min^{-1}gets 1st mark but not the 2nd]

Estimate of initial rate of gain of heat from surroundings:

$$\frac{\Delta Q}{\Delta t} = mc\frac{\Delta\theta}{\Delta t}$$

= (0.400 kg) (4200 J kg^{-1} K^{-1}) (0.033 K s^{-1})

= 50 → 71 W 3

[Allow 1st and 2nd marks if middle line is stated correctly.
Allow J min^{-1} if K min^{-1} is brought forward. Penalise inconsistent units.]

Explanation of twenty-seven minute delay:

Time needed for heat inflow to melt the ice [2/0] 2

Estimate of mass of ice initially present:

Energy absorbed $\Delta Q = \frac{\Delta Q}{\Delta t}\ t$ (1) = ml (1)

$m = \frac{(56\text{W})(27 \times 60\text{s})}{(2.27 \times 10^6\ \text{J})}$

= 0.035 kg $\rightarrow$ 0.051 kg 4

[Allow full credit for correct specific latent heat capacity value
(334 kg $\rightarrow$ 0.051 kg^{-1}) leading to 0.243 kg $\rightarrow$ 0.344 kg.]

[11]

6. Molecules get closer together **(1)**

PE molecules increase [Not k.e. increases, but ignore] **(1)**

Arrangement becomes disordered / regular arrangement breaks down lattice structure **(1)**

Bonds broken/weaken/overcomes intermolecular forces $\rightarrow$ melting
[Not forces broken/weaken] **(1)**

Molecules start to translate/free to move/ move over/round/
relative to each other **(1)** Max 2

Use of $E = Pt$ [Allow 36 – 39 minutes] **(1)**

Use of $E = ml$ **(1)**

$l = 3.3\ 10^5$ J kg^{-1} **(1)**
[Not converted to s $\rightarrow$ 5475 J kg^{-12} , gets 2/3] 3

Thermometer and clock	OR	Temperature sensor and datalogger [Not just computer] **(1)**
Read thermometer at regular or frequent times		Records temperatures at regular intervals **(1)**

[If interval specified allow = 10 min] 2

Lid / stir / keep thermometer away from heater / how to avoid parallax

Thermal equ heater /power supply constant/heater totally submerged **(1)** 1

Single horizontal line at 29°C **(1)**

Both gradients greater than water's **(1)**

Flat bit shorter than water [if two sloping bits are shown] **(1)** 3

[11]

7. Diagram:

Heater in aluminium block with suitably placed thermometer
Lagging round the surface of the block and
a circuit diagram with correctly placed voltmeter, ammeter and power supply 3

Measure the mass of the block (m) **(1)**
Record voltmeter and ammeter readings (V and I) **(1)**
Note time (t) heater on **(1)**
and initial (θ_1) and final (θ_2) temperature of block **(1)**
Energy transferred to block = IVt **(1)**
Increase in internal energy of block = $mc(\theta_2 - \theta_1)$ **(1)**

Specific heat capacity of aluminium $c = \frac{IVt}{m(\theta_2 - \theta 1)}$ **(1)** Max 6

[9]

8. Energy calculation

$\Delta Q = mc\Delta T$

$\Delta Q = 0.7 \text{ kg} \times 4200 \text{ J kg}^{-1} \text{ K}^{-1} \times 80 \text{ K}$ **(1)**

$\Delta Q = 235\,200$ (J) [or 235 (kJ)] [no u.e.] **(1)** 2

Time taken

$$\text{Time} = \frac{\text{Energy}}{\text{Power}}$$

$$\frac{235200\text{J}}{2200\text{W}}$$

Formula **(1)**
Substitution [Allow e.c.f.] **(1)**
Time = 106.8 s [or 110 s] **(1)** 3
[Allow use of 250 kJ to give 114 s]

Graph
Temperature becomes constant at the end **(1)**
Uniform rate of temperature rise/straight line in central region **(1)**
Initially rate slow, then rate increases, then rate decreases **(1)** 3

Efficiency
Efficiency = ratio of two times or two energies **(1)**
in range 0.67 – 0.78 **(1)** 2
[Allow their calculated time value and time off graph in range 145 s – 160 s]

[10]

9. Definition of specific latent heat of fusion

$L = \frac{\text{energy}}{\text{change in mass}}$ /energy to change 1 kg **(1)**

during a change of state/solid to liquid **(1)**

at constant temperature/at melting point **(1)** 3

Explanation of time interval AB

Energy used to break bonds/pull molecules apart/overcome forces of attraction **(1)** 1

Differences between solid and liquid states

Marks can be scored for diagrams and/or words

Any two rows:

Difference	Solid	Liquid	
Arrangement	Regular array OR lattice	No regular pattern	**(1)**
Motion	Vibrational motion	Random/Brownian Free to move around (each other)	**(1)**
Spacing	Close packed	*Slightly* further apart than in a solid	**(1)**

Max 2

[6]

10. Definition of specific heat capacity

Energy (needed) 1

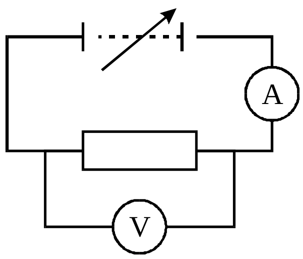
(per) unit mass/kg) 1
(per) unit temperature change/ °C / K)

OR

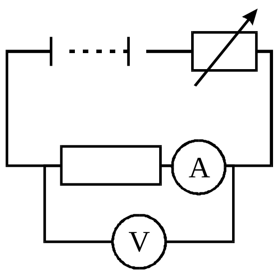
Correct formula [does not need to be rearranged] 1

with correctly defined symbols 1

Circuit diagrams



OR



Accept voltmeter across heater and ammeter as well as voltmeter across heater only

Means of varying p.d./current 1

Voltmeter in parallel with a resistor symbol 1

Ammeter in series with any representation of heater 1

Other apparatus

- (Top pan) balance / scales 1
- Stopwatch / timer / clock 1

Explanation

Energy/heat loss to surroundings/air/bench

OR

$mc\Delta\theta + \Delta Q = Vlt$ or equivalent in words (e.g. student ignores energy loss in calculations)

OR

$mc\Delta T + \Delta Q = Vlt$ or equivalent words 1

Modifications

Any two from

- Use of insulation around block
- Ensure all of heater is within block

Grease heater/thermometer 2

[10]

11. black or black cools quickly
better emitter (of heat) A1 OR better radiator/black radiates white doesn't
radiation/infra-red A1 of heat/infra-red
Accept in terms of white teapot (NOT better emitter and absorber/conductor)

[Total 3]

12. (a) mention of lower and upper fixed points or 0(°C) and 100(°C) or ice point/steam point B1 (marks made on) thermometer with ice/water mixture and (steam above) boiling water (at atmospheric pressure) B1 divided into 100 (equal) parts (accept 10 parts marked 10,20 etc.) B1
(b) (i) 120°C or –10°C to 110°C B1
(ii) each degree/scale marking/10°C/division is an equal distance/0.9–1.1mm/cm/expansion or appropriate graph a straight line B1
(c) 10°C and 20°C marks clearly further up thermometer and roughly equal spacing B1

[Total 6]

13. (a) (i) 24(°C) [1]

(ii) 6(°C); 4(°C) (ecf) [1]

(b) Heat lost to surroundings [1]

round flame/to gauze/tripod [1]

(c) Variable resistor [1]

TOTAL 5