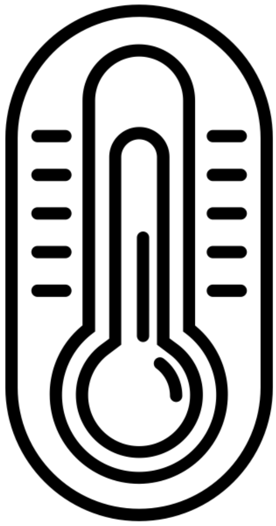
ESAT Physics Prep
Week 4 – Thermal physics



ANSWERS

Week 1 – Electricity

Week 2 – Magnetism

Week 3 – Mechanics

Week 4 – Thermal physics

Week 5 – Matter

Week 6 – Waves

Week 7 – Radioactivity

There is one sample ESAT test – note that they use the same questions from NSAA 2020 specimen paper. Past NSAA & ENGAA questions are the most relevant.

There are no calculators in the ESAT.

Thermal physics spec

P4.1 Conduction:

a. Know and understand thermal conductors and insulators, with examples.

b. Know and be able to apply factors affecting rate of conduction.

P4.2 Convection:

a. Understand and be able to apply the effect of temperature on density of fluid.

b. Understand and be able to apply fluid flow caused by differences in density.

P4.3 Thermal radiation:

a. Understand thermal radiation as electromagnetic waves in the infrared region.

b. Know and be able to apply absorption and emission of radiation.

c. Know and be able to apply factors affecting rate of absorption and emission of thermal radiation.

P4.4 Heat capacity:

a. Understand the effect of energy transferred to or from an object on its temperature.

b. Know and be able to apply: specific heat capacity $= \frac{\text{thermal energy}}{\text{mass} \times \text{temperature change}}$

where temperature is measured in °C and specific heat capacity, c, is measured in $\mathrm{J\,kg^{-1}\,°C^{-1}}$.

$$\frac{dQ}{dt} = \frac{kA\Delta T}{x}$$

k — Thermal conductivity ($\mathrm{Wm^{-1}K^{-1}}$)

A — heat transfer area

ΔT — Temperature difference

$\frac{dQ}{dt}$ — rate of heat transfer

x — distance

Q12 ENGAA 2023

12 A large, flat, metal plate is coated on one side with a layer of thermally insulating material of the same thickness a as the metal plate.

higher thermal conductivity

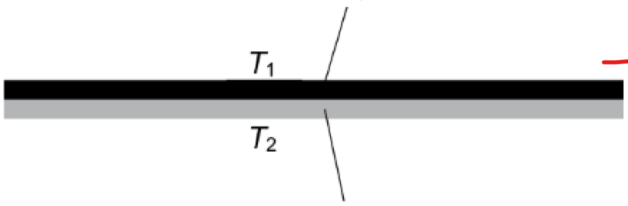
The uninsulated top surface of the metal plate is maintained at a constant temperature T_1.

The bottom surface of the insulating material is maintained at a constant, lower temperature T_2.

The system is in equilibrium.

The diagram shows this arrangement.

$\frac{dQ}{dt}$ is constant across both layers



$\frac{k_m A \Delta T_m}{a} = \frac{k_i A \Delta T_i}{a}$

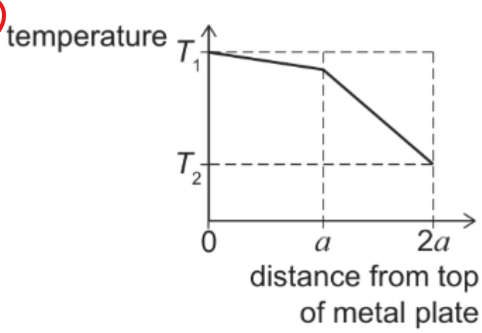
$k_m \Delta T_m = k_i \Delta T_i$

$\Delta T_m = \frac{k_i}{k_m} \Delta T_i$

$k_i < k_m$ so $\Delta T_m < \Delta T_i$

Which graph could show how the temperature varies with distance from the top surface of the metal plate to the bottom surface of the insulating material?

A



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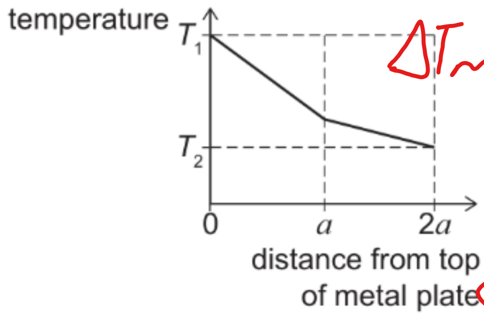

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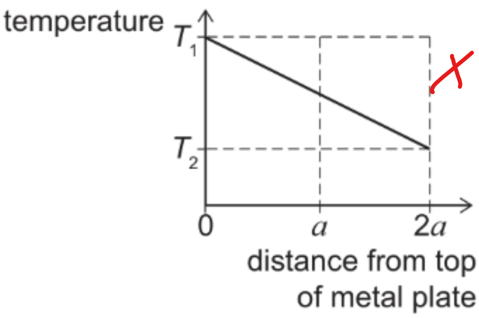

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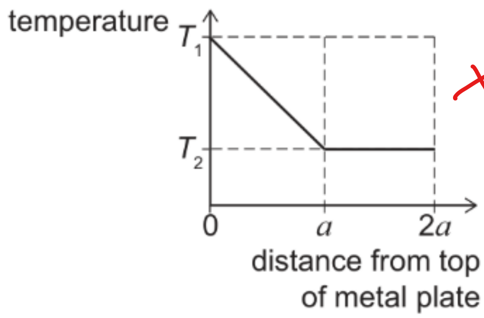
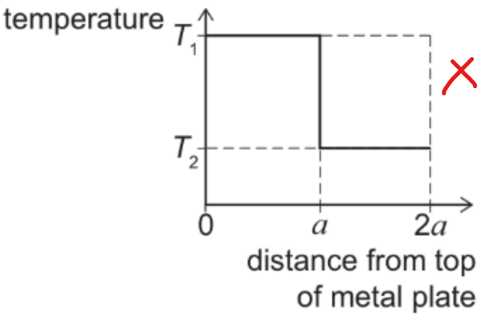


E



Q33 NSAA 2023

33 10 g of ice at 0 °C is added to 20 g of liquid water at 30 °C.

The mixture reaches thermal equilibrium.

What is its equilibrium temperature, T?

(specific latent heat of fusion of ice = 330 J g^{-1}
specific heat capacity of liquid water = 4.2 J g^{-1} °C^{-1}
assume that there is no heat transfer between the mixture and its surroundings)

A $T < 0$ °C

B $T = 0$ °C

C 0 °C $< T <$ 20 °C

D $T = 20$ °C

E 20 °C $< T <$ 30 °C

F $T = 30$ °C

G $T > 30$ °C

To melt ice $E = 10 \times 330$

To heat water $E = 10 \times 4.2 \times T$

To cool water $E = 20 \times 4.2 \times (30 - T)$

$(10 \times 330) + (10 \times 4.2T) = 20 \times 4.2 \times (30 - T)$

$330 + 4.2T = 8.4 \times (30 - T)$

$330 + 4.2T = 252 - 8.4T$

$12.6T = -80$

$T = \frac{-80}{12.6}$

negative so not all ice melts so $T = 0$°C

Q14 ENGAA 2022

14 A piece of metal of mass 50 g is at thermal equilibrium in a hot liquid at temperature *T*.

The metal is removed from the liquid and immediately placed in 100 g of water that is at 20 °C.

The water is stirred and reaches a final temperature of 26 °C.

material	*specific heat capacity* / $J\,kg^{-1}\,°C^{-1}$
hot liquid	2000
metal	350
water	4200

What is the temperature *T* of the hot liquid?

(Assume that heat transfers to or from the surroundings are negligible.)

A 38 °C

B 51 °C

C 150 °C

D 170 °C

E 480 °C

$$50 \times 350 \times (T - 26) = 100 \times 4200 \times 6$$

$$0.5 \times 350 \times (T - 26) = 4200 \times 6$$

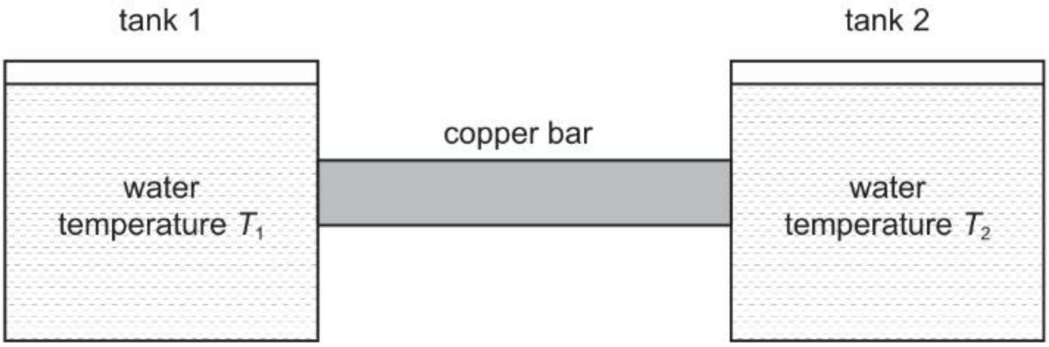
$$175 \times (T - 26) = 4200 \times 6$$

$$T = \frac{4200 \times 6}{175} + 26$$

$$= 170\ °C$$

Q23 NSAA 2022

23 The diagram shows a system consisting of two large copper tanks of water connected to each other by a solid cylindrical copper bar.



The temperature of the water in tank 1 is T_1. The water in tank 2 is at a higher temperature T_2.

The following four statements list changes that can be made, independently, to the system. At all times $T_1 < T_2$.

1 increase temperature T_1

2 increase temperature T_2

3 increase the length of the copper bar

4 increase the diameter of the copper bar

Which two changes each independently result in an increase in the rate of conduction of thermal energy along the copper bar?

A 1 and 2

B 1 and 3

C 1 and 4

D 2 and 3

E 2 and 4

F 3 and 4

Q18 ENGAA 2021

18 A beaker containing 180 g of water at 25 °C has a 20 g ice cube at 0 °C added to it.

No heat is transferred between the water and the surroundings (including the beaker).

What is the final temperature of all the water in the beaker after all the ice has melted?

(Take the specific heat capacity of water to be $4\,J\,g^{-1}\,°C^{-1}$ and the specific latent heat of fusion of water to be $300\,J\,g^{-1}$.)

A 2.5 °C

B 8.3 °C

C 10.0 °C

D 15.0 °C

E 16.7 °C

F 22.5 °C

$(20 \times 300) + (20 \times 4 \times T) = 180 \times 4 \times (25 - T)$

$6000 + 80T = 18000 - 720T$

$800T = 12000$

$T = \frac{120}{8} = 15\,°C$

Q20 ENGAA 2020

2 A soldering iron has a copper tip of mass 2.0 g.

The tip is heated with 30 W of thermal power. In 50 s, the temperature of the tip increases by 200 °C.

$E = Pt = 30 \times 50 = 1500\,J$

How much energy is transferred from the tip to the surroundings in this time?

(specific heat capacity of copper = $400\,J\,kg^{-1}\,°C^{-1}$)

A 160 J

B 500 J

C 1340 J

D 1500 J

E 1660 J

F 1840 J

G 2500 J

$E = mc\Delta T$

$= 0.002 \times 400 \times 200$

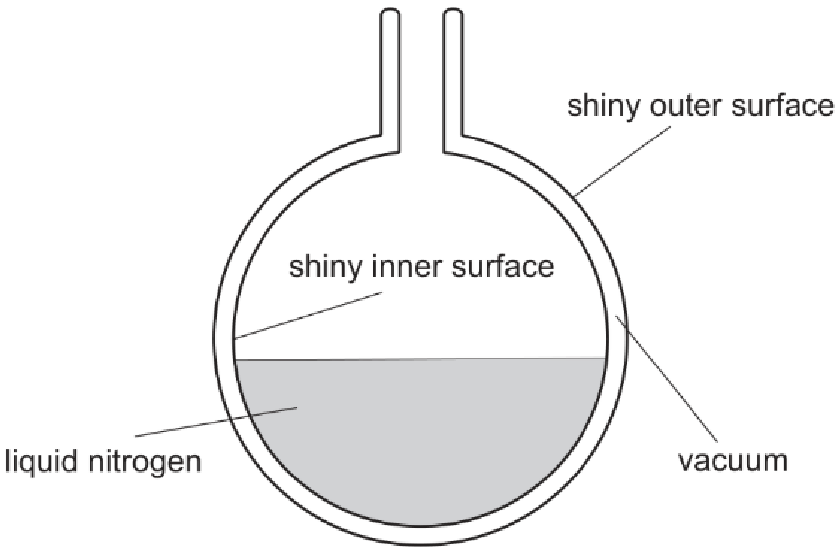
$= \frac{1}{500} \times 400 \times 200$

$= 0.8 \times 200 = 160\,J$

$1500 - 160 = 1340\,J$

Q26 NSAA 2020

26 In a laboratory, liquid nitrogen is stored at a very low temperature in the vessel shown in the diagram.



The vessel has a double wall made from a poor thermal conductor. There is a vacuum in the gap between the two walls.

The inner surface of the inner wall is shiny. The outer surface of the outer wall is shiny.

These features insulate the liquid nitrogen by reducing the rate at which thermal energy is transferred to the liquid nitrogen.

Which of the following statements explain(s) why these features help to insulate the liquid nitrogen?

1 The shiny inner surface of the inner wall is a good emitter of thermal radiation.

2 Thermal radiation cannot travel in a vacuum.

3 The shiny outer surface of the outer wall is a poor absorber of radiation.

A none of them

B 1 only

C 2 only

D 3 only

E 1 and 2 only

F 1 and 3 only

G 2 and 3 only

H 1, 2 and 3

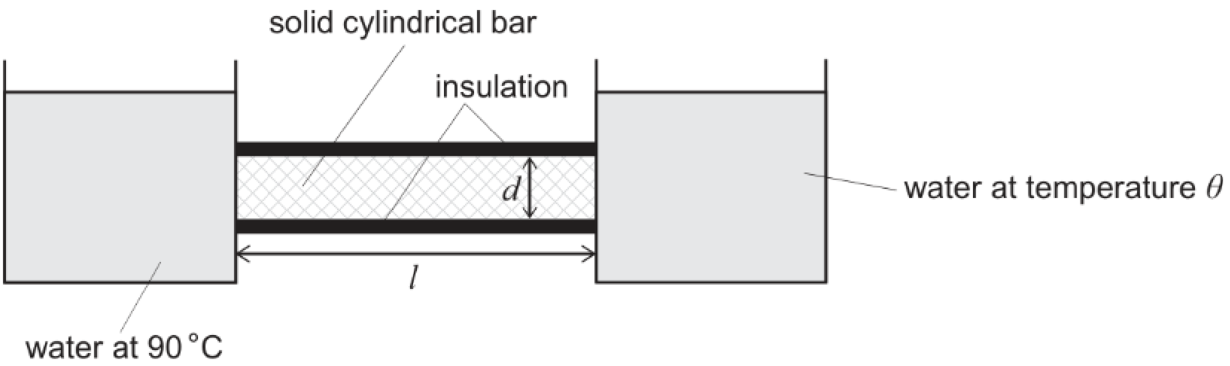
Q10 ENGAA 2019

$$\frac{dQ}{dt} = \frac{kA\Delta T}{x}$$

10 Two tanks of water are connected by a solid cylindrical copper bar of length l and diameter d.

The bar is insulated.

One tank contains water at 90 °C and the other tank contains water at temperature θ.



For which of the following conditions is thermal energy conducted along the bar at the lowest rate?

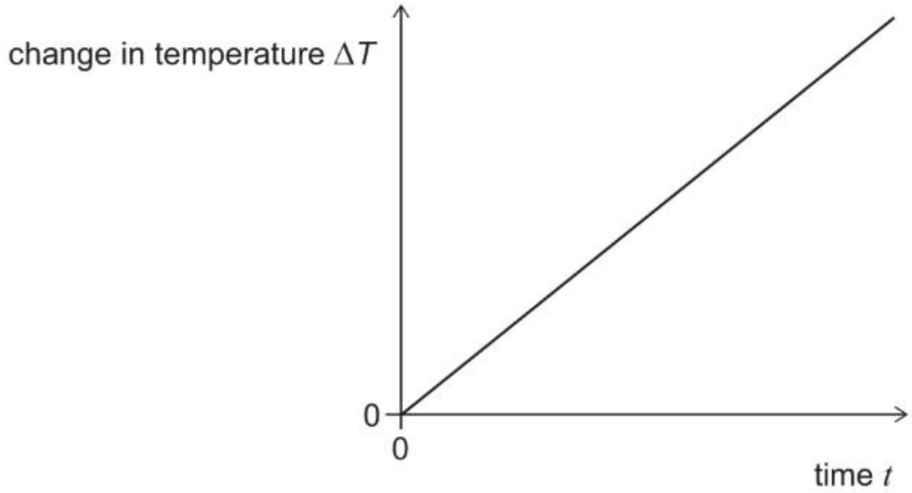
	l / m	d / cm	θ / °C
A	0.40	4.0	20
B	0.40	4.0	40
C	0.40	8.0	20
D	0.40	8.0	40
E	0.80	4.0	20
F	0.80	4.0	40
G	0.80	8.0	20
H	0.80	8.0	40

Q35 NSAA 2021

35 A metal block has mass M.

Heat is transferred to the block at a constant rate P.

The graph shows how the change in temperature ΔT of the block from its initial temperature varies with time t.



The gradient of the line is k.

Which expression gives the specific heat capacity of the metal from which the block is made?

(Assume that no heat is transferred out of the block during the time interval shown by the graph.)

A $\frac{1}{MPk}$

B $\frac{M}{Pk}$

C $\frac{Mk}{P}$

D $\frac{P}{Mk}$

E $\frac{PM}{k}$

F $\frac{Pk}{M}$

G $\frac{k}{MP}$

H MPk

$$E = mc\Delta T$$

$$Pt = mc\Delta T$$

$$\frac{\Delta T}{t} = \frac{P}{mc} = k$$

$$c = \frac{P}{mk}$$

Q23 NSAA 2019

23 A block of aluminium of mass 0.80 kg, initially at a temperature of −21 °C, is supplied with 54 000 J of thermal energy.

The specific heat capacity of aluminium is 900 J kg^{-1} °C^{-1}.

What is the final temperature of the block?

(Assume that there is no other transfer of energy between the block and the surroundings.)

A 27 °C

B 39 °C

C 54 °C

D 75 °C

E 96 °C

$E = mc\Delta T$

$\Delta T = \frac{E}{mc}$

$= \frac{54000}{0.80 \times 900}$

$= \frac{540}{0.80 \times 9}$

$= \frac{540}{7.2}$

$= 75\ °C$

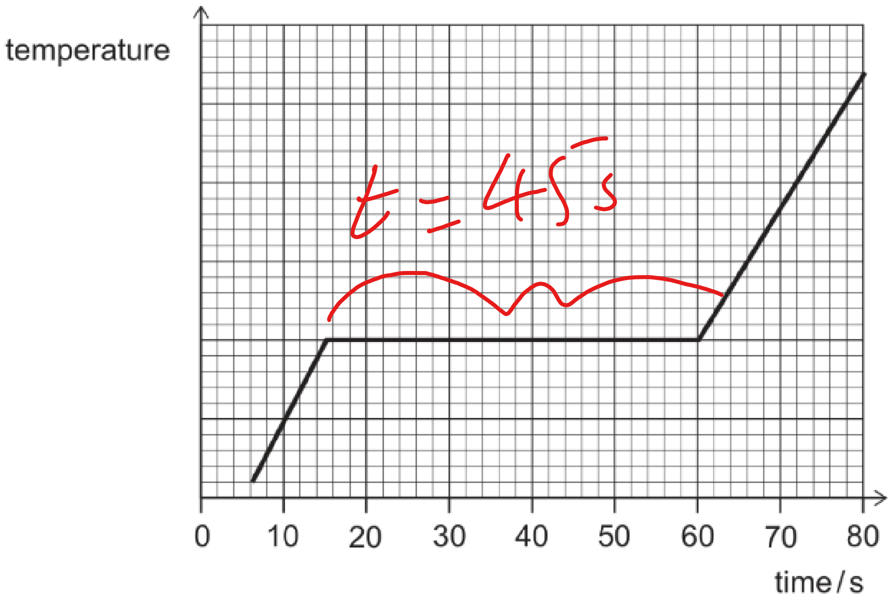
$75 - 21 = 54\ °C$

Q27 NSAA 2019

$\Rightarrow E = Pt = 60 \times 45 = 2700\,J$

27 Heat is supplied to an initially solid substance at a rate of 60 W.

The graph shows the variation of the temperature of the substance with time.



What is the mass of the substance?

(specific latent heat of fusion of substance = 100 J g^{-1}; assume that there is no heat transferred to the surroundings)

A 0.013 g

B 0.60 g

C 3.0 g

D 9.0 g

E 27 g

F 36 g

$E = mL$

$m = \frac{E}{L} = \frac{2700}{100} = 27\,g$

Q4 ENGAA 2017

4 When a saucepan of water is heated from below, convection currents form and transfer heat through the liquid.

Here are three statements about the water as it is heated:

1 The mass of a fixed volume of the water increases. ✗

2 The density of a fixed mass of the water decreases. ✓

3 The volume of a fixed mass of the water increases. ✓

Which of these statements help(s) to explain how convection currents are formed?

A none of them

B 1 only

C 2 only

D 3 only

E 1 and 2 only

F 1 and 3 only

G 2 and 3 only

H 1, 2 and 3