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Mana Tohu Mātauranga o Aotearoa
New Zealand Qualifications Authority

Level 1 Physics 2023

90939 Demonstrate understanding of aspects of heat

Credits: Four

Achievement	Achievement with Merit	Achievement with Excellence
Demonstrate understanding of aspects of heat.	Demonstrate in-depth understanding of aspects of heat.	Demonstrate comprehensive understanding of aspects of heat.

Check that the National Student Number (NSN) on your admission slip is the same as the number at the top of this page.

You should attempt ALL the questions in this booklet.

Make sure that you have Resource Sheet L1–PHYSR.

In your answers use clear numerical working, words, and/or diagrams as required.

Numerical answers should be given with an appropriate SI unit.

If you need more room for any answer, use the extra space provided at the back of this booklet.

Check that this booklet has pages 2–12 in the correct order and that none of these pages is blank.

Do not write in any cross-hatched area (). This area will be cut off when the booklet is marked.

YOU MUST HAND THIS BOOKLET TO THE SUPERVISOR AT THE END OF THE EXAMINATION.

QUESTION ONE: DATA STORAGE

Modern data centres run tens of thousands of servers (computers). These produce a lot of heat.

To help cool the servers, many data centres use ‘hot aisles/cold aisles’ layouts. The server racks are aligned with their heat exhausts facing each other. This forms a ‘hot aisle’. The hot air from the server rack rises in the hot aisle enclosure. The air is drawn away, cooled by a CRAC (computer room air conditioner), and directed back at the server racks as shown in the diagram below.

Source: https://journal.uptimeinstitute.com/a-look-at-data-center-cooling-technologies/

(a) State the name of the process of heat transfer by hot air rising.

(b) Discuss, in terms of kinetic theory, why hot air rises in the hot aisle enclosure.

(c) The heat output of a server is often measured in British Thermal Units (BTU) per hour. One BTU is the amount of energy required to raise the temperature of one pound of water (0.454 kg) by one degree Fahrenheit (0.556 °C).

Calculate the amount of energy in one BTU.

State your answer in Joules.

The specific heat capacity of water is 4182 J kg^{-1} $°C^{-1}$.

(d) The hot air is cooled down by CRACs. These require energy to run.

One server produces 34.5 MJ (34.5×10^6 J) of heat in 24 hours. Running the CRACs requires an **additional** amount of electric energy that equals 89% of the power that the servers produce as heat.

Calculate the **total power** required by a data centre that runs **25 000 servers**.

QUESTION TWO: IMMERSION COOLING

Some data centres use ‘immersion cooling’ methods to help cool their servers. For these methods, the computers are submerged in a tank of liquid coolant. A system of pumps draws the warm liquid coolant out and replaces it with cool liquid.

Source: https://www.akcp.com/blog/liquid-cooling-data-centers/

(a) Define the term ‘specific heat capacity’.

A particular server rack contains 64 servers of 250 W each. The rack is submerged in a tank of 967 kg of liquid coolant. This liquid coolant has a specific heat capacity of 1100 J kg^{-1} $°C^{-1}$.

(b) Show that the temperature of the liquid coolant increases by 0.90 °C every minute if no liquid is replaced.

(c) The specific heat capacity of the liquid coolant is 1100 J kg^{-1} $°C^{-1}$, which is larger than that of dry air, 1006 J kg^{-1} $°C^{-1}$.

Discuss which coolant, the liquid or air, will leave the tank at a lower temperature after running the servers for one hour.

(d) Heat is transferred from the servers to the liquid coolant by means of conduction.

Discuss why conduction to a liquid is more effective than conduction to a gas (such as air).

In your answer, you should:

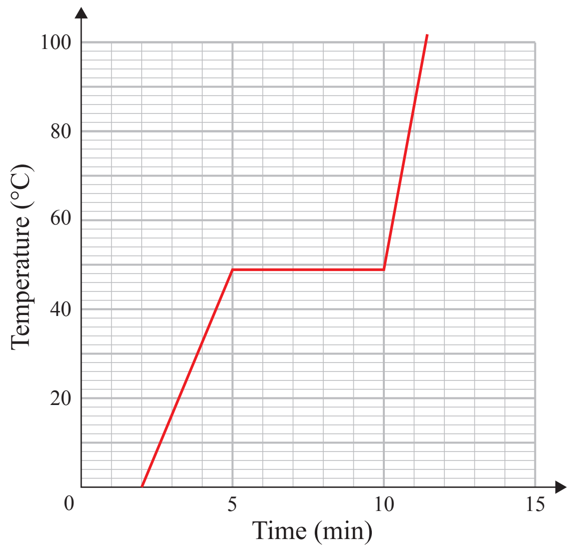
- describe, in terms of particle motion, what 'heat' is
- describe and explain conduction in terms of kinetic theory.

QUESTION THREE: TWO-PHASE COOLING

‘Two-phase cooling’ systems are a variant of immersion cooling. The difference is that the liquid two-phase coolant is allowed to evaporate. The warm vapour is carried away, condensed back to the liquid, cooled, and re-supplied to the system.

Source: https://images.anandtech.com/doci/15122/IMGP4762.jpg

The heating curve of a particular two-phase coolant is shown below, where the coolant was heated at a constant rate.



(a) Using information from the heating curve, determine the boiling point of the two-phase coolant.

Question Three continues on the next page.

(b) Compare the liquid and gaseous states of matter in terms of their particles.

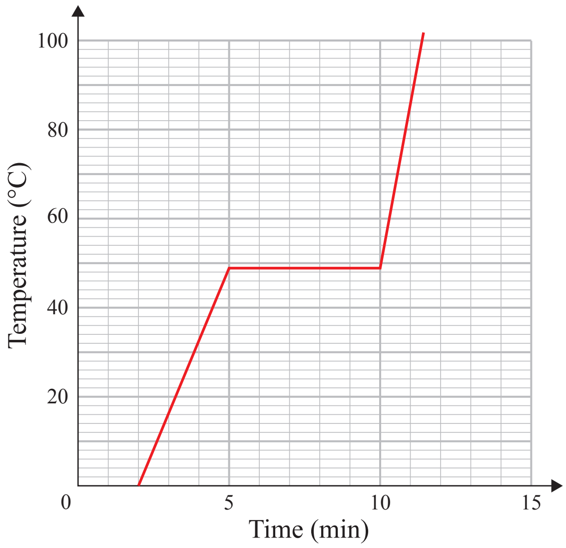
In your answer, you should describe:

- average inter-particle distances
- particle motion and average particle speeds
- average particle energies.

Liquid state	**Gaseous state**

(c) Discuss in terms of kinetic theory why the temperature does not increase between 5 and 10 minutes, as shown on the graph in part (a), even though heat energy is supplied to the coolant at a constant rate.

(d) In the heating curve of a particular two-phase coolant shown below, the coolant was heated at a constant rate of 14.5 kW.



Calculate the mass in kilograms of the two-phase coolant that was evaporated.

The latent heat of evaporation of the two-phase coolant is 88 000 J kg^{-1}.

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