Cambridge Assessment International Education

# Cambridge Pre-U

**PHYSICS** **9792/02**

Paper 2 Written Paper **May/June 2023**

INSERT

*1808445386-I*

**INSTRUCTIONS**

- The question in Section 2 of Paper 2 will relate to the subject matter of the extracts within this insert.
- You will have received a copy of this booklet in advance of the examination.
- The extracts on the following pages are taken from a variety of sources.
- Cambridge International does not necessarily endorse the reasoning expressed by the original authors, some of whom may use unconventional physics terminology and non-SI units.
- You should use all your knowledge of physics when answering the questions.



This document has **8** pages.

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## Extract 1: The caloric theory

By the late 1700s, the experiments of Fahrenheit, Black and others had established a systematic, quantitative way of measuring temperatures, heat flows and heat capacities, but this didn't really throw any new light on just what was flowing.

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When two solids are rubbed together, some caloric is squeezed out at the surfaces, or perhaps tiny pieces of material are rubbed off, and lose their caloric, so heat appears.

## Extract 2: Count Rumford's cannon experiment

'An Inquiry concerning the Source of the Heat which is excited by Friction' is a scientific paper by Benjamin Thompson, Count Rumford, which was published in the Philosophical Transactions of the Royal Society in 1798.

Rumford was an opponent of the caloric theory of heat which held that heat is a fluid that could be neither created nor destroyed. He had observed the frictional heat generated by boring out cannon barrels at the arsenal in Munich. At that time, cannons were cast at the foundry with an extra section of metal forward of what would become the muzzle and this section was removed and discarded later in the manufacturing process. Rumford took an unfinished cannon and modified this section to allow it to be enclosed by a water-tight box while a blunted boring tool was used on it. He showed that water in this box could be boiled within roughly two and a half hours and that the supply of frictional heat was seemingly inexhaustible.

Rumford confirmed that no physical change had taken place in the material of the cannon by comparing the specific heat capacities of the material machined away and the material remaining were the same. He argued that the seemingly indefinite generation of heat was incompatible with the caloric theory. He contended that the only thing communicated to the barrel was motion.

## Extract 3: James Prescott Joule and the mechanical equivalent of heat

During the mid-1800s, many scientists accepted the caloric theory of heat, which considered heat to be a fluid that could neither be created nor destroyed and which flowed from warm bodies to cold ones.

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Some scientists were sceptical about whether the experiments could be accurate enough, but, in the end, Joule's work stood the test of time and was confirmed by others.

**Extract 4: The second law of thermodynamics and heat engines**

The first law of thermodynamics is (an example of) the principle of conservation of energy. The second law (of thermodynamics) deals with the direction of changes in spontaneous processes. In spontaneous heat transfer, heat is transferred from the hotter object to the colder one, as shown in Fig. E4.1.

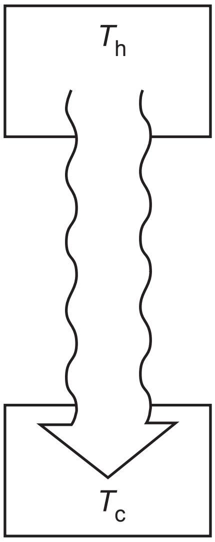


**Fig. E4.1**

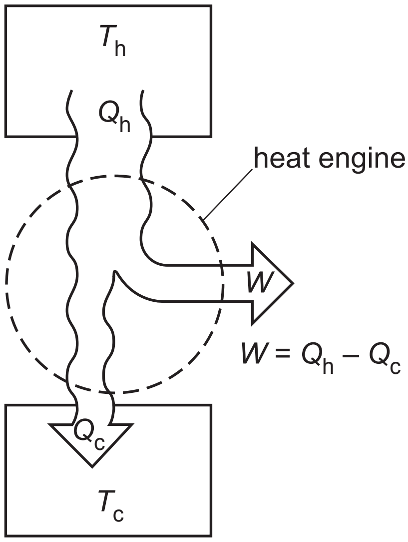


**Fig. E4.2**

A heat engine is a device that uses heat transfer to do work, shown schematically in Fig. E4.2.

Fig. E4.3 is a simplified diagram of an early heat engine produced by James Watt. Valve A allows steam from the boiler (the heat source) to push the piston up. Valve A is closed and valve B is opened allowing the steam into the condenser (the heat sink), where it condenses, lowering the pressure in the cylinder, and the piston falls.

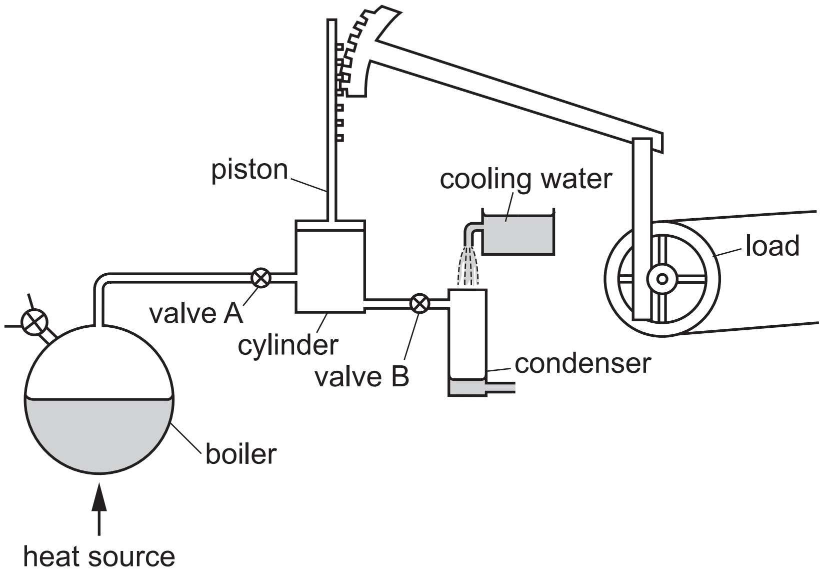


**Fig. E4.3**

Heat engines do work by using part of the heat transfer from some source. Heat transfer from the hot object (the heat source) is denoted as $Q_h$, while heat transfer into the cold object (the heat sink) is $Q_c$, and the work done by the engine is $W$. The temperatures of the hot and cold reservoirs are $T_h$ and $T_c$, respectively, where the temperatures are measured in kelvin.

The efficiency of conversion of energy to work is given by

$$\text{efficiency} = \frac{W}{Q_h} = \frac{Q_h - Q_c}{Q_h} = 1 - \frac{Q_c}{Q_h}.$$

For a theoretically perfect heat engine

$$\frac{Q_c}{Q_h} = \frac{T_c}{T_h}$$

so the maximum possible efficiency of a heat engine = $1 - \dfrac{T_c}{T_h}$.

## Extract 5: Refrigerators

Refrigerators and air conditioners transfer heat from cold to hot. They are heat engines run backwards. This requires work input $W$, which is also converted to heat transfer. Thus the heat transfer to the hot reservoir in Fig. E5.1 is $Q_h = Q_c + W$. (Note that $Q_h$, $Q_c$ and $W$ are positive, with their directions indicated on schematics rather than by sign.) A heat pump's mission is for heat transfer $Q_h$ to occur from a cooler environment into a warmer one, such as a home in the winter. The mission of air conditioners and refrigerators is for heat transfer $Q_c$ to occur from a cool environment into a warmer one, such as chilling a room or keeping food at lower temperatures than the environment.

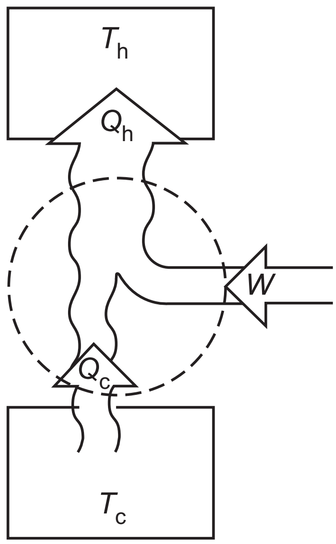


**Fig. E5.1**

The best refrigerator is one that removes the greatest amount of heat $Q_c$ from the inside of the refrigerator for the smallest amount of work $W$. Accordingly, the coefficient of performance (COP) of a refrigerator is the ratio

$$\text{COP} = \frac{Q_c}{W} = \frac{Q_c}{Q_h - Q_c}.$$

## Extract 6: Heat pumps

A heat pump is a device used to warm and sometimes also cool buildings by transferring thermal energy from a cooler space to a warmer space using the refrigeration cycle, being the opposite direction in which heat transfer would take place without the application of external power. Common device types include air-source heat pumps, ground-source heat pumps, water-source heat pumps and exhaust-air heat pumps. Heat pumps are also often used in district heating systems.

The efficiency of a heat pump is expressed as a coefficient of performance (COP), or seasonal coefficient of performance (SCOP). The higher the number, the more efficient a heat pump is and the less energy it consumes. At its most inefficient, $Q_c$ would be zero so that a heat engine would have a COP = 1, but typical values are much better than that, typically >2. When used for space heating, heat pumps are typically much more energy-efficient than simple electrical resistance heaters.

### Air-source heat pump

Air-source heat pumps are used to move heat between two heat exchangers; one outside the building which is fitted with fins through which air is forced using a fan and the other which either heats the air inside the building directly or heats water which is then circulated around the building through radiators. These devices can also operate in a cooling mode where they extract heat via the internal heat exchanger and eject it into the ambient air using the external heat exchanger.

Air-source heat pumps are relatively easy and inexpensive to install and are the most widely used heat pump type. In mild weather, the COP may be around 4.0, while at temperatures below around 0 °C an air-source heat pump may still achieve a COP of 2.5.

### Geothermal (ground-source) heat pump

A ground-source heat pump draws heat from the soil or from groundwater. The ground stays at a relatively constant temperature of about 6 °C all year round below a depth of about 9 m. A well-maintained ground-source heat pump will typically have a COP of 4.0 at the beginning of the heating season and a SCOP of around 3.0 as heat is drawn from the ground. Geothermal heat pumps are more expensive to install due to the need for the drilling of boreholes for vertical placement of heat exchanger piping or the digging of trenches for horizontal placement of the piping that carries the heat exchange fluid (water with a little antifreeze).

A geothermal heat pump can also be used to cool buildings during hot days, thereby transferring heat from the dwelling back into the soil via the ground loop.