Access Tuition

A-Level Physics

Second Law and Engines

Question Paper

Time available: 62 minutes
Marks available: 35 marks

1. (a) Which is a correct statement about an ideal heat engine?

Tick (✓) **one** box.

The efficiency is increased when the kelvin temperatures of the hot source and the cold sink are increased by equal amounts.	☐
The maximum efficiency depends on the p–V cycle.	☐
The efficiency is 50% when the kelvin temperature of the hot source is twice the kelvin temperature of the cold sink.	☐

(1)

(b) An ideal heat engine has an efficiency of 0.33
The same engine works in reverse as an ideal refrigerator between the same hot and cold spaces.

Determine the coefficient of performance COP_{ref} of the refrigerator.

COP_{ref} = ________________

(2)

(Total 3 marks)

2. (a) Explain how the second law of thermodynamics predicts that a heat engine can never be 100% efficient.

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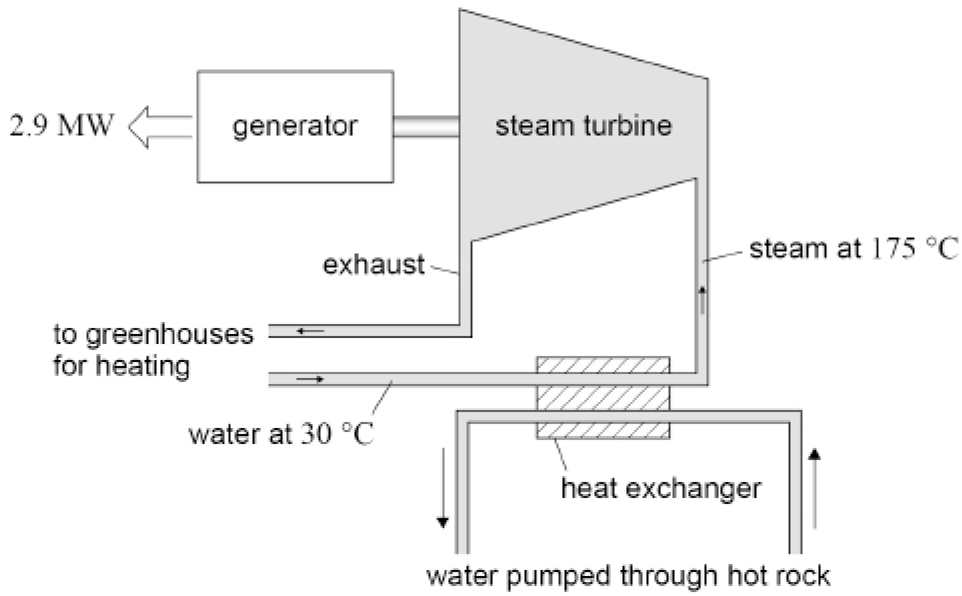
(2)

(b) A company plans to build a geothermal power station in a region where there is hot rock deep below the surface. The scheme is shown in the figure.



In the heat exchanger, energy from the hot rock is used to produce steam at 175 °C.
The steam passes through a turbine that drives an electric generator.
The exhaust steam is used to heat nearby greenhouses where it condenses before returning to the heat exchanger.

The lowest temperature in the turbine cycle is 30 °C.

The company claims that when the electrical power output is 2.9 MW, the power station will provide 6.4 MW for heating the greenhouses.

Deduce whether this claim is likely to be true.
Treat the power station as an ideal heat engine which obeys the second law of thermodynamics.

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(4)
(Total 6 marks)

3. A company claims to be able to provide a combined heat and power plant for a market garden that requires both electrical power and space heating for greenhouses. The engine-driven generator will operate between temperatures of 1450 K and 310 K.

(a) Show that the maximum theoretical efficiency of any heat engine operating between temperatures of 1450 K and 310 K is about 80%.

(1)

(b) The company makes the following two claims about the performance of the plant:

- **Claim 1** When consuming biogas of calorific value 55.5 MJ m^{-3} at the rate of 5.00×10^{-3} m^3 s^{-1}, the electrical power output will be 210 kW.
- **Claim 2** At the same time the engine will provide heating for greenhouses at the rate of at least 55.0 kW.

Discuss the extent to which the company's claims are justified.

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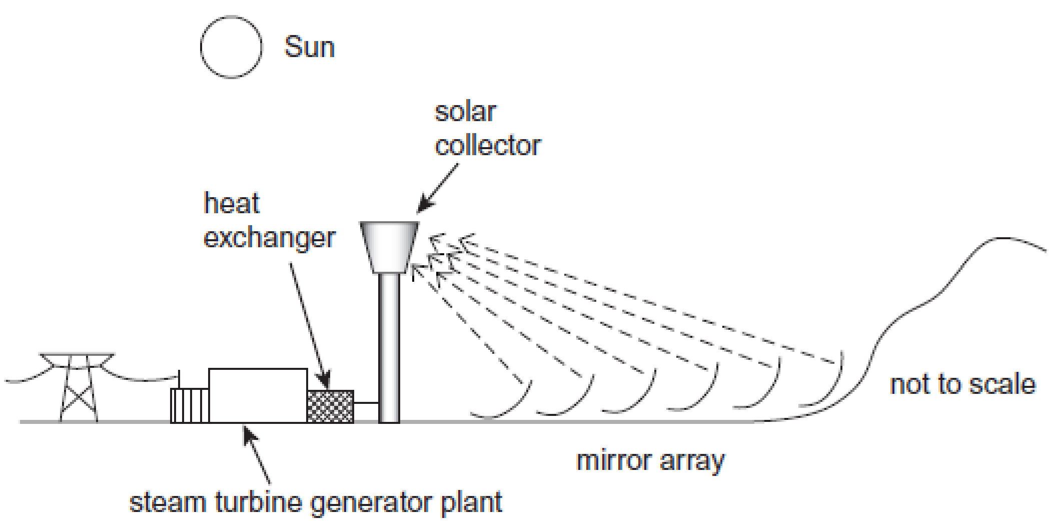
(5)

(Total 6 marks)

4. The diagram below shows the basic arrangement of a solar thermal power station. An array of mirrors tracks the Sun and reflects the Sun's rays onto a solar collector tower containing molten salt. The molten salt reaches a temperature of 540 °C. In the heat exchanger, the internal energy in the salt is transferred to water which turns to steam and drives a steam turbine generator to produce electricity. The steam turbine rejects energy to the atmosphere at 25 °C.



(a) Calculate the maximum theoretical efficiency of a heat engine operating between temperatures of 540 °C and 25 °C.

maximum efficiency = ____________________

(2)

(b) On one particular day the output of the power station is 48 MW. Calculate the input power to the power station assuming it can run at its maximum theoretical efficiency.

input power = ____________________ W

(1)

(c) The actual efficiency of the steam turbine is about 38% when the molten salt is at 540 °C. State **two** reasons why the actual efficiency of the power station is much less than the maximum theoretical efficiency.

1. ____

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2. ____

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(2)

(Total 5 marks)

5. A heat pump is used for heating a small workshop. The heat pump extracts energy from a patch of ground outside the workshop. The coefficient of performance of the heat pump is 3.2 and the average electrical power input is 780 W.

(a) (i) Calculate the rate at which energy is delivered to the workshop.

answer = ______________________ W

(1)

(ii) Calculate the rate at which energy is extracted from the ground.

answer = ______________________ W

(1)

(b) A student claims: "A heat pump delivers more energy than is supplied to it". Discuss this statement and explain why a heat pump does not contradict the law of conservation of energy or the second law of thermodynamics.

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(3)

(Total 5 marks)

6. **Figure 1** shows the energy transfers in an ideal heat engine operating between a source of heat at a temperature of 640°C and a cold heat-sink at a temperature of 20°C.

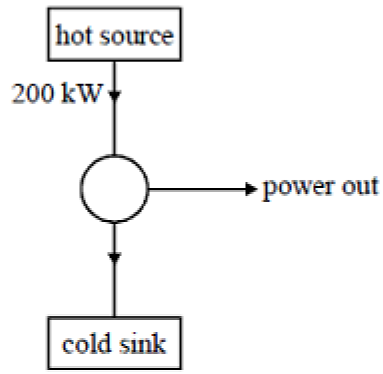

Figure 1

(a) Calculate

(i) the maximum possible efficiency,

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(ii) the maximum power output corresponding to this efficiency if the rate of energy supply from the hot source is 200 kW.

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(3)

(b) A designer states that the two-stage ideal heat engine shown in **Figure 2**, below, would operate at a greater overall efficiency, and hence provide a greater total power output, than the engine of **Figure 1**. The same heat source and sink are to be used, but the energy rejected from the first stage enters a reservoir which acts as a source of energy for the second stage. The temperature of the reservoir is such that the maximum possible efficiency of the first stage is 34% and that of the second stage is 52%.

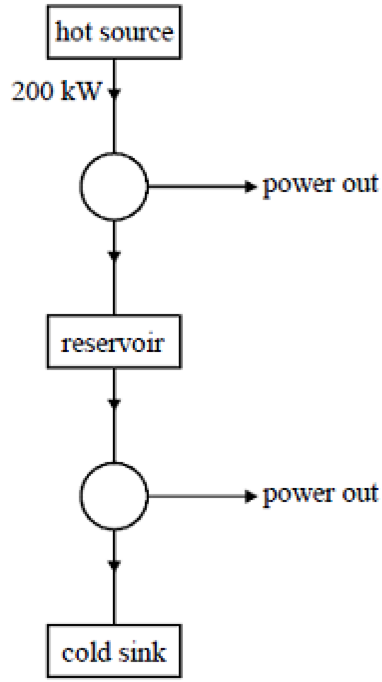

Figure 2

For the two-stage engine, operating at its maximum theoretical efficiency, calculate

(i) the power output of the first stage,

(ii) the power delivered to the reservoir from the first stage,

(iii) the power output of the second stage,

(iv) the overall efficiency of the two-stage engine.

(4)

(c) Comment on the validity of the designer's statement.

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(3)

(Total 10 marks)