Unit 5 · Second Law of Thermodynamics

HARDER PRACTICE QUESTIONS

Full marks 30

Write your answers on separate paper. Show your working.

1 Spot the error [3]

Find the mistake in the working and correct it.

A Carnot engine works between a source at 227 °C and a sink at 27 °C. Nisha finds its efficiency: "$\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{27}{227} = 0.88 = \mathbf{88\%}$."

2 A real setting [4]

The numbers are made up, but of the right size.

A power station's boiler makes steam at 820 K, and its condenser is cooled by a river at 310 K. It gives out 500 MW of electrical power with an efficiency of 38%.

i. Find the best efficiency any engine could have between these temperatures.

ii. Find the heat the station takes from its fuel each second.

iii. Find the heat it gives to the river each second.

3 Check the claim [3]

A company advertises a refrigerator with a coefficient of performance of 12, keeping its inside at −5 °C in a kitchen at 30 °C. Could the claim be true? Show your working.

4 Show that [3]

Two Carnot engines work one after the other: the first takes heat from a source at T_1 and gives its waste heat to a reservoir at T, from which the second takes it and gives out its waste to a sink at T_2. Show that the two engines have the same efficiency when $T = \sqrt{T_1 T_2}$. Find T for $T_1 = 800$ K and $T_2 = 320$ K.

5 Predict, then explain [3]

Write your prediction first, then explain it.

A room is to be kept at 20 °C while the air outside is at 5 °C. One way is an electric heater; the other is a heat pump, a refrigerator that takes heat from the outside air and gives it out in the room.

i. Predict: for each kilojoule of electrical energy, which puts more heat into the room?

ii. Find the most heat an ideal heat pump could give the room for 1 kJ.

6 Read the data [3]

Answer from the data.

The ideal efficiencies of a petrol engine with different compression ratios are:

Compression ratio r	4	6	8	10	12
Efficiency (%)	42.6	51.2	56.5	60.2	63.0

i. Does doubling the compression ratio from 4 to 8 double the efficiency?

ii. Use the value at r = 8 to find the γ of the working gas.

7 What if? [3]

A diesel engine has a compression ratio of 16 and a cut-off ratio of 2.5 ($\gamma = 1.4$). Its ideal efficiency is $1 - \frac{1}{r^{\gamma-1}} \times \frac{\rho_c{}^{\gamma} - 1}{\gamma(\rho_c - 1)}$. What if a petrol engine could be run at the same compression ratio? Compare their ideal efficiencies, and say why petrol engines aren't built that way.

8 Correct the misconceptions [3]

The paragraph has three mistakes. Write each mistake and correct it.

Rohan wrote: "A good enough engineer could build a heat engine with no sink that turns all its heat into work; only friction stops us now. A Carnot engine using steam is more efficient than one using air between the same temperatures. And a refrigerator destroys heat, which is why its inside gets cold."

9 Think [3]

2500 J of heat flows straight from a body at 480 K to a body at 240 K (both too large for their temperatures to change). Find the change in the total entropy. How much work could a Carnot engine have done with the same 2500 J between these bodies? What does this tell you about the heat flow?

10 Make your own [2]

Design a Carnot engine with an efficiency of 25% that gives its waste heat to a river at 15 °C. Give the temperature of its source, and the heat it must take in to do 900 J of work.