Thermal Physics: Thermodynamics - Assessment 2 Feedback

> "Thermodynamics is a funny subject. The first time you go through it, you don't understand it at all. The second time you go through it, you think you understand it, except for one or two small points. The third time you go through it, you know you don't understand it, but by that time you are so used to it, it doesn't bother you anymore."

— Arnold Sommerfeld c.1950

1 Part (a)

Most people understood first law and used it correctly.

Very few people got (a) part (ii) correct, with most quoting KP and Clausius versions of the 2nd law and making statements such as "no heat flows from cold to hot thus second law is satisfied", without a further investigation of the efficiency of the heat transfer. In this problem we had multiple bodies, so the simplest approach is to start from the Clausius inequality, which is easily seen to be violated.

Some students also attempted to find an equivalent system or Carnot engines, to show that the efficiency of the given engine was greater than the equivalent Carnot engines, but very few managed to do it correctly. One cannot:

- just use the hottest reservoir
- naively substitute $T_1 \to Q_1$, etc...
- show that the effiency of both carnot engines individually are less than the efficiency of the given system.

The correct way to calculate the Carnot efficiency would have been to use

$$\frac{Q_1}{T_1} + \frac{Q_2}{T_2} - \frac{Q_3}{T_3} = 0 \, , \tag{1}$$

for a reversible process, but on the way to doing this one could have seen that the Clausius inequality was violated.

2 Part (b)

Generally well done. Some students did not notice that there are two different $PV(T)$ y-axes which correspond to two systems at different T's , and so the values substituted for some of the calculations were incorrect. Few students did not state the assumptions they made (i.e that working in the low P regime allows to consider gas as the ideal one).

3 Part (c)

Some students started with the expansion seen in a previous problem set then plugged in the ideal gas law to get the final answer. This “works” but requires you to essentially replace a PV term on the RHS of the equation despite their already being a PV on the LHS which is clearly not that of an ideal gas! Plugging in the ideal gas law was essentially a shortcut through some differentiation and Taylor expansion work.

4 Part (d)

Well done. Some students confused about signs of coefficients a and b, and some thought that these were functions of temperature – they are material-dependent constants. Some students did not read the question carefully and did not comment on the slope of the line. The best way of approaching this problem was to investigate the functional form of the slope found in (c) and its dependence on T in the high T limit.

Many students thought that a was some kind of measure of ‘anti-interaction’ with the boundaries of the container, confusing the origin of a with the effect it has on P.

5 Parts (e) and (f)

Generally well done. Some students had problems with integrating the functions of the $T^{-3}\mathrm{d}T$ form. Due to the negative exponent one should consider the change of sign in front of the resultant function, which was not so obvious for some of the students. If it’s any consolation, anywhere where it was possible to make a sign error, someone made it.

Many students also seemed to think that

$$\frac{1}{T_f - T_i} = \frac{1}{T_f} - \frac{1}{T_i} \tag{2}$$

which is wrong!

6 Part (g)

Answered well, but many students did not answer the last part though. This might again come from the fact that some of the students did not read the question carefully. Entropy is a state function, thus since taking any substance once round a cycle returns it to the same (initial) state, there can be no change in it’s entropy.

7 Part (h)

Probably the part which the most people struggled with. The heat q could be obtained using a similar procedure to parts (e) and (f). One common problem was obtaining an expression for q for the constant pressure process, writing $q = C_P dT = C_P \Delta T$. However, in part (e), or just from $C_P = (\frac{\mathrm{d}H}{\mathrm{d}T})P$, we find that C_P is a function of T and can't be taken outside of the integral. Some students derived the correct equations for heats/entropies, but did not use them to evaluate the required sum and did not show that it is indeed less than zero.

It's also useful to remember that rearranging things into the form $(\text{something})^2$ is useful for figuring out whether things are positive or negative.

8 Part (i)

Some students did not realise that

$$\Delta S_{universe} = \Delta S_{substance} + \Delta S_{surroundings} \ . \tag{3}$$

Since in (g) you have proven that their is no entropy change for the substance going round the cycle. Thus

$$\Delta S_{universe} = \Delta S_{surroundings} \tag{4}$$

The main source of problems was that some did not figure out that (g) implies the above relationship. The final step is to realise that in the case of the surroundings, the process is the same as in (h) but with the heat flows q_i reversed, and thus

$$\Delta S_{universe} = -\sum_i \frac{q_i}{T_{res}} > 0 \tag{5}$$

from (h). Some did not include the minus sign and hence got the entropy of the universe is decresasing, which would violate the 2nd Law of Thermodynamics.

In such cases, a sanity check is always recommended.