The following questions come from recent examination papers and, as such, are good examples of the type of question that will appear on your examination paper. The marks allocated also indicate, in minutes, the amount of time available under exam conditions to do the questions.

1. Describe two methods of increasing the total internal energy of a metal bar.  
   4 marks

2. State in words the first law of thermodynamics.  
   If a system does 1000 joules of external work on its surroundings and 300 joules of heat flows into the system from the surroundings, does the internal energy of the system increase or decrease? By how much?  
   6 marks

3. Estimate the efficiency of photosynthetic conversion of radiant solar energy into the internal energy of agricultural produce from the following data:  
   CORNFIELD
   - Growing season: 100 days.
   - Plot size: 1.0 hectare \((10^4 \text{ m}^2)\).
   - Number of plants per plot: \(2.0 \times 10^4\).
   - Average mass of plant: 0.50 kg.
   - 24-hour average radiant power intensity on earth's surface: 0.20 kW.m\(^{-2}\).
   - Energy content of 1.0 kg of plant material: 20 MJ.  
   6 marks

4. What is a thermometric property?  
   The diagram shows the thermal EMF for a thermocouple as a function of temperature difference. Comment on the suitability of the thermocouple for use as a thermometer in the temperature range \(T_A\) to \(T_C\).  

   ![Thermal EMF Diagram](image)

   6 marks

5. (a) Name two convenient fixed points for checking the calibration of a thermometer in the temperature range 250 K to 400 K.  
   (b) In each of the following thermometers, what is the thermometric property used to measure temperature?  
      - Mercury-in-glass thermometer.
      - Thermistor thermometer.
      - Constant volume gas thermometer.
      - Thermocouple thermometer.  
   6 marks
6. How could you measure the temperature of a bathful of water? How could you measure the temperature of a thimbleful of water? Give reasons for your answers.  

6 marks

7. Consider two mercury-in-glass thermometers, one placed in the shade, the other in direct sunlight. Which of the thermometers gives a better estimate of the temperature of the surrounding air? Discuss.  

7 marks

8. (a) Explain the significance of the zeroth law of thermodynamics.  

2 marks

(b) With the aid of a labeled diagram describe the construction of a triple point cell.  

4 marks

(c) Write down the conventional definition of the ideal gas temperature scale. Describe how the triple point temperature is used in that definition.  

2 marks

(d) Explain why the triple point of water is such a convenient fixed point for use in this definition.  

2 marks

9. Suggest suitable forms of thermometer for the following applications.  

(a) Measuring the temperature of a horse’s blood.  

(b) Measuring the temperature of boiling liquid oxygen.  

(c) Measuring the temperature of molten iron in a blast furnace.  

(d) Measuring the temperature of an incandescent lamp filament.  

In each case give a reason for your choice.  

8 marks

10. A thermocouple was calibrated against an accurate thermometer. The following data were obtained.  

<table>
<thead>
<tr>
<th>TEMPERATURE MEASURED BY THERMOMETER / °C</th>
<th>THERMOCOUPLE METER READING / mV</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10.5</td>
<td>0.67</td>
</tr>
<tr>
<td>24.0</td>
<td>1.47</td>
</tr>
<tr>
<td>34.0</td>
<td>2.02</td>
</tr>
</tbody>
</table>

(a) On the graph paper provided, draw a calibration curve for the thermocouple.  

(b) Estimate the temperature corresponding to a reading of 1.00 mV.  

8 marks

11. Suppose that as a result of eating breakfast a person’s internal chemical energy increases by 3 MJ. Suppose that the person then commences to work and that for each joule of external work performed the body generates 9 joules of heat. When the internal chemical energy of the body has reached its pre-breakfast value again, how much external work will the person have done? Using the data below determine:  

(a) by how much the person’s body temperature would rise if the body could not lose the heat generated;  

(b) how much perspiration the body must secrete if all the heat is lost evaporatively.  

Data. Mass of person: 70 kg.  

Specific heat of person: 3.5 kJ.kg⁻¹.K⁻¹.  

Latent heat of vaporization of water at body temperature: 2.4 MJ.kg⁻¹.  

9 marks

12. Is the specific heat of water greater than or less than the specific heat of most other substances? When 1 kg of water is mixed with 1 kg of another substance at a different temperature, which suffers the greater temperature change? Explain.  

3 marks
13. During training, the body mass of a greyhound decreases by 0.2 kg. Calculate the thermal energy dissipated by evaporation of saliva during this time.

Latent heat of vaporization of water at body temperature: 2.4 MJ kg\(^{-1}\).

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14. Give an example of
(i) an adiabatic change,
(ii) an isochoric change,
(iii) an isobaric change.

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15. State which of the following processes are adiabatic, which are isochoric and which are isobaric.
(a) The rapid compression of air in a bicycle pump.
(b) The oxidation of alcohol in a bomb calorimeter (a closed metal container).
(c) The slow inflation of a balloon.
(d) The melting of a block of ice.

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16. Define *latent heat of fusion*.

A 0.75 kg block of ice at 0\(^\circ\)C has 0.50 L of boiling water poured on to it.

(i) Does all the ice melt?
(ii) What is the final temperature of the system of the original ice plus the water?
(iii) What is the change in internal energy of the system?

Latent heat of fusion of water = 335 kJ kg\(^{-1}\).
Specific heat of water = 4.2 kJ kg\(^{-1}\). K\(^{-1}\).

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17. A copper cup, insulated on the outside, contains a mixture of ice and water. Initially the cup contained 0.200 kg of ice at 0 \(^\circ\)C. 1.000 kg of water at 100.0 \(^\circ\)C was added and the final equilibrium temperature was 65.0 \(^\circ\)C.

(a) Calculate
(i) the change in internal energy of the ice as it melts and rises to 65.0 \(^\circ\)C.
(ii) the change in internal energy of the hot water, and
(iii) the heat capacity of the cup.

(b) State any assumptions you make.

Data: specific heat of water: 4.18 kJ kg\(^{-1}\). K\(^{-1}\);
latent heat of fusion of water: 335 kJ kg\(^{-1}\).

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18. A 1.25 kW electric jug element is immersed in 1.00 kg of water at 20\(^\circ\)C.
Estimate the time taken for half the water to boil away.

Data: specific heat of water: 4.2 kJ kg\(^{-1}\). K\(^{-1}\);
latent heat of vaporization of water: 2.26 MJ kg\(^{-1}\).

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19 When an electric current flows in a coil of copper wire, the temperature of the coil continually rises. If the coil is cooled by a flow of water past it while the electric current is flowing through it the temperature reaches a steady value. Figure 1 shows the temperature of the coil vs time if the coil is thermally isolated from its surroundings. Figure 2 shows the effect of water cooling.

![Fig. 1](chart1.png)  
![Fig. 2](chart2.png)

(a) Suppose the power dissipated in the coil is 500 W. Calculate the heat capacity of the coil.
(b) Explain why the rate that energy is carried away by the flowing water at \( t = 8 \) min is also 500 W.
(c) Suppose the temperature of the water before it flows past the coil is 20 °C and the temperature of the water flowing out is 40 °C. At what rate does water must flow past the coil to carry away this energy? In your answer use the unit \( \text{kg.s}^{-1} \).

[Specific heat of water = 4.2 \text{ kJ.kg}^{-1}.\text{K}^{-1}]

13 marks

20 The heat absorbed by a gas in some process that takes place at constant pressure is given by

\[ Q = \Delta U + P \Delta V \, . \]

(a) Explain the meaning of each symbol on the right-hand side.
(b) Show how this follows from the first law of thermodynamics.
(c) Explain the connection between the above expression for the heat absorbed and Hess's law.

9 marks

21 One definition of entropy is: Entropy is a measure of the randomness of a system. Give brief descriptions of two examples to illustrate this definition.

6 marks
22 Figure A shows the set-up for a diffusion demonstration. An hour after the partition is removed the two gases are completely mixed (figure B).

![Diagram showing the diffusion demonstration](image)

(a) Is the process reversible? Explain.
(b) Has the total entropy of the air and the bromine increased or decreased? Explain. 6 marks

23 When a quantity of steam in a glass flask at 100°C suddenly condenses to water it is clear that there is an increase in order amongst the water molecules.

Has the second law of thermodynamics been violated? Write down expressions for entropy changes to support your claim. 9 marks

24 The sun, whose surface temperature is about 6000 K, radiates with a power of about \(4 \times 10^{26}\) W. What is the maximum decrease in entropy the sun could experience in a day? 6 marks

25 What is the theoretical upper limit to the amount of work per cycle which can be obtained from this engine?

![Diagram of an engine cycle](image)
26 Consider two engines.

![Diagram showing two engines E1 and E2 with heat and work](image)

The energies quoted are for one cycle of operation of the engines.

For both engines:

(i) Calculate the heat lost to the cold reservoir.
(ii) Calculate the entropy changes in the hot reservoir, the cold reservoir and the engine.
(iii) Can the engine operate?  

9 marks

27 Consider the following devices.

A. A refrigerator that, without any work being done, transfers in each cycle of operation, 500 J from a system at 200 K to the surroundings at 280 K.
B. An engine that in each cycle of operation receives 1000 J from a high temperature reservoir at 500 K and supplies the 1000 J to do useful work.

Calculate the entropy changes involved in each for these devices and indicate which devices, if any, cannot operate.

10 marks

28 Calculate the theoretical upper limit to the amount of work per cycle which can be obtained from this cyclic device.

![Diagram showing a cyclic device](image)  

9 marks

29 The contents of a refrigerator are at 270 K, the room outside is at 300 K. Calculate the maximum rate at which energy can be removed from the contents if the power consumed by the refrigerator is 1.00 kW.

8 marks
30 A steam engine takes steam from a boiler at 200°C and exhausts it to the atmosphere at 100°C.

\[
\begin{align*}
\text{BOILER} & \quad 200 \, ^\circ \text{C} \\
\text{Heat transferred per cycle} & = Q_1 \\
\text{STEAM ENGINE} & \quad \text{Work out per cycle} = W \\
\text{Heat transferred per cycle} & = Q_2 \\
\text{ATMOSPHERE} & \quad 100 \, ^\circ \text{C}
\end{align*}
\]

(a) Consider one cycle of operation and, using the symbols and information in the diagram, write expressions for
(i) the change in entropy of the boiler,
(ii) the change in entropy of the atmosphere, and
(iii) the change in entropy of the engine.

(b) Calculate the upper limit on efficiency, imposed by the second law, of the engine operating under these conditions.

\[
\text{Efficiency} = \frac{W}{Q_1}
\]

31 A steam engine uses steam that has been heated to 250 °C in a boiler to move a piston. During the second half of the cycle, the steam is condensed into water at 40 °C.

(a) Calculate the theoretical maximum work that can be done by the engine in one cycle if the heat flowing into the engine from the steam is \(1.0 \times 10^5\) joules per cycle.

(b) How could the engine be made to operate more efficiently?

32 Explain, in terms of entropy, why an energy flow through a biological system is necessary to keep the system alive.

33 One of the most widely used arguments in the controversy between the creationist theory of the origin of life on earth and the darwinian theory of evolution involves the second law of thermodynamics. Very crudely this argument says that evolution from non-living to living matter must involve a decrease in entropy and therefore contravenes the second law.

(a) Is it true to say that the entropy of a planet might decrease if life evolved? Why?

(b) Is the anti-darwinian argument given above valid or not? Why?

34 (a) What are the three rules that govern the changes that occur within biological cycles?

(b) Discuss briefly how each of these rules might apply to astronauts living for a long time in a space station in orbit around the earth

35 Describe a free expansion.

Is there a temperature change in the free expansion of an ideal gas? Explain your answer.
36 In a free expansion, gas is allowed to expand into an evacuated vessel. The boundaries of the system of gas, tap, and evacuated vessel are adiabatic.

(a) Is the work done by the gas on its surroundings negative, positive or zero? Explain your answer. 2 marks

(b) Is the change in internal energy of the gas negative, positive or zero? Explain your answer. 3 marks

(c) Does the temperature change for an ideal gas undergoing such an expansion? Explain your answer. 2 marks

(d) Does the temperature change for a real gas undergoing such an expansion? Explain your answer. 2 marks

37 (a) Explain the terms
(i) critical temperature,
(ii) maximum inversion temperature.
(b) Describe the free expansion of a gas.
(c) Describe the throttling of a gas.
(d) Describe the liquefaction of a gas by throttling. 12 marks

38 The diagram shows an isotherm for a real gas. The state of the gas can be changed from the state represented by point A to the state represented by point B by compressing it at constant temperature. Describe what happens to the gas during this change, indicating in what phases the gas exists in the regions 1, 2, and 3. Pressure

Volume 6 marks
What do you understand by the term partial pressure?
Two isotherms of the pressure-volume graph for water are shown below.

Suppose the air temperature is 25 °C.
What is the state of the water if the partial pressure for water is
(i) 2.0 kPa?
(ii) 3.4 kPa?  

With the aid of pressure-volume isotherms, explain the following phenomena:-
(a) Droplets of water form on a glass of cold lemonade.
(b) Water in a glass vessel boils furiously when the air is pumped out of the vessel.

A person who is perspiring feels cooler if there is a wind blowing or if there is a fan operating. Explain this.

A piece of plastic foam and a piece of metal have been lying on a table for a while. The plastic feels warm to the touch while the metal feels cold. Explain.

Show that small animals that are being heated by the sun cannot make as effective use of evaporative cooling as large animals.

Explain the function of the glass walls and roof of a greenhouse.

Describe and discuss the mechanisms of heat transfer from the human body.

The rate at which energy is radiated from a surface of area $A$ at a temperature $T$ is given by the Stefan-Boltzmann equation

$$ P = \varepsilon \sigma A T^4 $$

where $\varepsilon$ is the emissivity of the surface and $\sigma$ is the Stefan-Boltzmann constant

$[\sigma = 5.67 \times 10^{-8} \text{ W.m}^{-2}\text{.K}^{-4}]$.

In a warm room in which the temperature is 29 °C, a naked resting person has a skin temperature of 33 °C. The exposed surface area is 1.5 m$^2$. The emissivity of the person is 1.0.

Calculate the net radiative rate of heat transfer from the person.
47 (a) Explain the meaning of the term *black body radiation*. 2 marks

(b) Consider two black bodies at different temperatures. Sketch, on a single set of axes, graphs showing the relation between the power emitted per unit area per unit wavelength interval and the wavelength. Indicate which graph represents the higher temperature. 4 marks

(c) If the temperature of the sun were suddenly to *increase* (but its size were to stay the same) how would the following quantities change at the surface of the earth?
- The total radiant power received.
- The wavelength for maximum spectral intensity of received radiation.
- The radiant power received in the visible range. 3 marks

48 (a) Calculate the energy required to melt 5.0 kg of ice at 0 °C. 3 marks

(b) Write down an expression for the rate at which heat flows through a slab of material. Explain what each symbol means. 4 marks

(c) A container made of an insulating material is filled with 5.0 kg of ice at 0 °C. How long does it take the ice to melt?

Suppose that
- surface area of container = 0.20 m²;
- thickness of container = 0.010 m;
- coefficient of thermal conductivity for the insulating material = 0.050 W.m⁻¹.K⁻¹;
- temperature outside the container = 30 °C;
- latent heat of fusion of water = 3.0 × 10⁵ J.kg⁻¹. 10 marks

49 Consider the design of solar water-heating systems.

(a) Visible light from the sun is absorbed by the solar collector. What kind of radiation is re-emitted into the surroundings by the solar collector? Explain. 3 marks

(b) Solar collectors are usually specially coated to improve their performance. The amount of radiation absorbed or emitted by a collector depends on the wavelength. The properties of one recently discovered coating are shown below.

![Diagram of energy absorbed and emitted vs. wavelength](image)

Explain why these properties make it a particularly suitable coating. 8 marks

50 In a Thermos flask, all the ways of heat transfer are minimized. How? 6 marks
51 (a) An ideal gas has an equation of state

\[ PV = nRT. \]

Define each symbol in this equation.

(b) At the bottom of a lake where the temperature is 7 °C, the pressure is 280 kPa. An air bubble of diameter 4.0 cm at the bottom rises to the surface, where the temperature is 27 °C. What is the diameter of the bubble at the surface?

(Ignore the contribution to pressure from the water vapour.)

52 Explain how (i) temperature and (ii) total internal energy of a system may be changed.
Can one be changed without the other? Explain with illustrations.

53 A heat pump is required to transfer 3.0 kW of power from the outside of a room at 10 °C to the inside at 21 °C.

(i) What will be the rate of entropy change of the outside air?
(ii) What must be the minimum rate of entropy increase for the inside air?
(iii) If the pump is 100% efficient how much external power must be supplied to the pump?