S4 Physics Practice Paper (Set 1): Heat Energy and Specific Heat Capacity, Latent Heat and Changes of State, Gas Laws and the Ideal Gas, Kinetic Theory, Thermal Conduction and Insulation, Household Energy Efficiency (100 marks)

S4 Physics | Time: 75 minutes | Total: 100 marks | 24 questions

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Section A: Heat Energy and Specific Heat Capacity (16 marks)

Show all working. Specific heat capacities: water 4200 J/(kg C), aluminium 900 J/(kg C), copper 390 J/(kg C). Ignore heat losses unless stated otherwise.

1. 2.0 kg of water is heated from 20 C to 60 C. Find the energy required and express it in kJ.

Q = mcDT = 2.0 x 4200 x 40 = 336000 J = 336 kJ.

2. A 1500 W heater of 80%% efficiency heats 1.5 kg of aluminium from 15 C to 95 C. Find the energy needed and the heating time.

Q = 1.5 x 900 x 80 = 108000 J; useful power = 1500 x 0.80 = 1200 W; t = 108000 / 1200 = 90 s.

3. 0.30 kg of water at 80 C is added to 0.20 kg of water at 20 C. Find the final steady temperature.

Heat lost equals heat gained: (0.30 x 80 + 0.20 x 20) / 0.50 = 56 C, i.e. 56 C.

4. A 0.50 kg copper block at 100 C is placed in 0.40 kg of water at 20 C. Find the final temperature.

0.50 x 390 x (100 - T) = 0.40 x 4200 x (T - 20); 195(100 - T) = 1680(T - 20); T = 53100 / 1875 = 28.3 C.

Section B: Latent Heat and Changes of State (17 marks)

Specific latent heat of fusion of ice 3.34 x 105 J/kg, of vaporisation of water 2.26 x 106 J/kg, specific heat capacity of water 4200 J/(kg C).

5. 0.25 kg of ice at 0 C is melted completely to water at 0 C. Find the energy required.

Q = mL = 0.25 x 3.34 x 105 = 83500 J.

6. The 0.25 kg of water at 0 C is then heated to 100 C. Find the energy required.

Q = mcDT = 0.25 x 4200 x 100 = 105000 J.

7. The 0.25 kg of water at 100 C is then vaporised completely. Find the energy required.

Q = mL = 0.25 x 2.26 x 106 = 565000 J.

8. Find the total energy for the three steps, and the time needed with a 2000 W heater of 100%% efficiency.

Total = 83500 + 105000 + 565000 = 753500 J; t = 753500 / 2000 = 376.8 s (about 6.3 min).

Section C: Gas Laws and the Ideal Gas (17 marks)

Take the ideal gas constant R = 8.31 J/(mol K) and absolute temperature T = theta + 273 K.

9. A fixed mass of gas occupies 3.0 dm3 at 2.0 x 105 Pa. The pressure is raised to 6.0 x 105 Pa at constant temperature. Find the new volume.

Boyle law p1V1 = p2V2: V2 = (2.0 x 105 x 3.0) / 6.0 x 105 = 1 dm3.

10. Gas sealed in a rigid container is at 1.5 x 105 Pa at 27 C. It is heated to 127 C at constant volume. Find the new pressure.

T1 = 300 K, T2 = 400 K; p2 = 1.5 x 105 x 400 / 300 = 2.0 x 105 Pa.

11. Find the number of moles in 0.024 m3 of oxygen at 1.0 x 105 Pa and 27 C. Given molar mass 32 g/mol, find its mass.

n = pV / RT = (1.0 x 105 x 0.024) / (8.31 x 300) = 0.963 mol; mass = 0.963 x 32 = 30.8 g.

12. Find the volume of 1.0 mol of ideal gas at 1.0 x 105 Pa and 273 K, in m3 and in dm3.

V = nRT / p = (1.0 x 8.31 x 273) / 1.0 x 105 = 0.0227 m3 = 22.7 dm3.

Section D: Kinetic Theory of Gases (16 marks)

Boltzmann constant k = 1.38 x 10-23 J/K, R = 8.31 J/(mol K). Root-mean-square speed v = sqrt(3RT/M) with M in kg/mol.

13. A gas is heated from 300 K to 600 K. Find the ratio of the root-mean-square molecular speeds.

v varies as sqrt(T), so v2/v1 = sqrt(600 / 300) = 1.414.

14. Find the mean translational kinetic energy of a gas molecule at 300 K.

E = 3/2 kT = 1.5 x 1.38 x 10-23 x 300 = 6.21 x 10-21 J.

15. Nitrogen has molar mass 0.028 kg/mol. Find the root-mean-square speed of nitrogen molecules at 300 K.

v = sqrt(3 x 8.31 x 300 / 0.028) = sqrt(267107) = 516.8 m/s.

16. Hydrogen has molar mass 0.002 kg/mol. Find its root-mean-square speed at 300 K and the ratio to nitrogen.

v = sqrt(3 x 8.31 x 300 / 0.002) = 1934 m/s; ratio = 1934 / 516.8 = 3.74.

Section E: Thermal Conduction and Insulation (17 marks)

Rate of conduction Q/t = kADT / d, with k = 0.60 W/(m K) for glass. Electricity costs $1.2 per kWh.

17. A glass pane of area 1.5 m2 and thickness 5 mm has a 20 C temperature difference across it. Find the heat conducted per second.

Q/t = 0.60 x 1.5 x 20 / 0.005 = 3600 W.

18. The pane is replaced by glass of the same type but 12 mm thick, other conditions unchanged. Find the heat conducted per second.

Q/t = 0.60 x 1.5 x 20 / 0.012 = 1500 W.

19. Find the ratio of the heat transfer rates for the 5 mm and 12 mm panes, and explain why double glazing saves energy.

Ratio = 3600 / 1500 = 2.4. Greater thickness means greater thermal resistance, and the trapped still air layer in double glazing conducts poorly, so heat transfer falls sharply.

20. Taking the 12 mm pane, find the energy lost through the window in one day (24 hours) in kWh and the equivalent electricity cost.

Energy = 1500 x 24 x 3600 = 1.296 x 108 J = 36 kWh; cost = 36 x 1.2 = $43.2.

Section F: Household Energy Efficiency and Cost (17 marks)

Specific heat capacity of water 4200 J/(kg C). Electricity $1.2 per kWh, gas $0.30 per kWh of energy content. Give money answers to 2 decimal places.

21. A 3.0 kW electric heater raises 50 kg of water from 20 C to 60 C at 100%% efficiency. Find the energy and the time.

Q = 50 x 4200 x 40 = 8.4 x 106 J; t = 8.4 x 106 / 3000 = 2800 s (about 46.7 min).

22. If the heater is only 85%% efficient, find the electrical energy actually consumed and the heating time.

Electrical energy = 8.4 x 106 / 0.85 = 9.88 x 106 J; t = 9.88 x 106 / 3000 = 3294 s (about 54.9 min).

23. Find the electricity used (kWh) and the cost in the 85%% case.

Electricity = 3.0 kW x (3294 / 3600) h = 2.75 kWh; cost = 2.75 x 1.2 = $3.29.

24. A gas heater is 70%% efficient. Find the gas cost per kWh of useful heat and the percentage saving against electricity at $1.2 per kWh and 85%% efficiency.

Gas cost per useful kWh = 0.30 / 0.70 = $0.43; electricity cost per useful kWh = 1.2 / 0.85 = $1.41; saving = (1.41 - 0.43) / 1.41 x 100% = 64.3%.

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