

1. How much work is done if 240 L of argon gas irreversibly double in volume against 1 bar of pressure?

- ☐ 240 J
- ☐ 2.4 kJ
- ☒ 24 kJ
- ☐ 240 kJ

✓ **Correct**

If the argon doubles in volume, the volume increase is 240 L, which is 0.24 m^3 . $1 \text{ bar} = 100,000 \text{ Pa}$.

The work done is the pressure multiplied by the change in volume, thus

$$100,000 \text{ Pa} \times 0.24 \text{ m}^3 = 24,000 \text{ J or}$$

24 kJ.

2. An exothermic reaction releases 146 kJ of heat energy and 3 mol of gas at 298 K and 1 bar pressure. Which of the following statements is correct?

- ☐ $\Delta U = -138.57 \text{ kJ}$ and $\Delta H = -138.57 \text{ kJ}$
- ☐ $\Delta U = -153.43 \text{ kJ}$ and $\Delta H = -153.43 \text{ kJ}$
- ☐ $\Delta U = -138.57 \text{ kJ}$ and $\Delta H = -146.00 \text{ kJ}$
- ☒ $\Delta U = -153.43 \text{ kJ}$ and $\Delta H = -146.00 \text{ kJ}$

✓ **Correct**

298 K and 1 bar represent SATP, standard ambient

temperature and pressure. Under these conditions the gas molar volume

is 24.78 dm^3 . Thus $3 \times 24.78 \text{ dm}^3$ of gas

are released which equals 74.34 dm^3 or 0.07434 m^3 . If you didn't know the molar volume you can work out the

volume of gas released using $V = nRT/p = 3 \text{ mol} \times 8.314 \text{ J K}^{-1} \text{ mol}^{-1} \times 298 \text{ K} / 100,000 \text{ Pa} = 0.07433 \text{ m}^3$. The slight difference is simply a rounding

error. $w_{on} = -p\Delta V = -100,000 \text{ Pa} \times 0.07433 \text{ m}^3 = -7,433 \text{ J}$ or -7.433 kJ . The

reaction is exothermic so $q_{in} = -146 \text{ kJ}$. Finally

$\Delta U = q_{in} + w_{on} = -146 \text{ kJ} - 7.43 \text{ kJ} = -153.43 \text{ kJ}$. Under isobaric conditions $\Delta H = q_p = -146 \text{ kJ}$.

3. 4.4 kg of carbon dioxide gas, CO_2 , undergo isothermal expansion at 298 K from a volume of 2 to 5 m³ in three steps of 1 m³. Assuming ideal gas behaviour, what is the total work performed by the gas?

- ☒ 194 kJ
- ☐ 245 kJ
- ☐ 387 kJ
- ☐ 461 kJ

✓ **Correct**

4.4 kg = 4,400 g = 4,400 g/44 g mol⁻¹ = 100 mol. Using $p = nRT/V$ where $n = 100$ mol, $R = 8.314$ J K⁻¹ mol⁻¹, $T = 298$ K and $V = 3, 4$ and 5 m³

respectively gives pressures of 82,586, 61,939 and 49,551 Pa. Work done = $p\Delta V = 82,586$ Pa \times 1 m³ = 82,586 J, 61,939 Pa \times 1 m³ = 61,939 J and 49,551 Pa \times 1 m³ = 49,551 J. Total work = 82,586 J + 61,939 J + 49,551 J = 194,076 J or 194 kJ.

4. 4.4 kg of carbon dioxide gas, CO_2 , undergo reversible isothermal expansion at 298 K from a volume of 2 to 5 m³. Assuming ideal gas behaviour, what is the total work performed by the gas?

- ☐ 138 kJ
- ☒ 227 kJ
- ☐ 294 kJ
- ☐ 362 kJ

✓ **Correct**

$W_{on} = -nRT \ln (V_f/V_i) = -100 \text{ mol} \times 8.314 \text{ J K}^{-1} \text{ mol}^{-1} \times 298 \text{ K} \times \ln (5 \text{ m}^3/2 \text{ m}^3) = -227,018 \text{ J}$. The value

is negative because we calculated w_{on} , the work done on the system. The actual work done by the gas is positive and hence 227 kJ. This is the maximum work that could possibly be achieved from this gaseous expansion.

5. How much expansion work is done on the system when exactly 1 mol of solid ammonium chloride, NH_4Cl , decomposes completely

to yield gaseous ammonia, NH_3 , and hydrogen chloride, HCl , at

a temperature of 1280 K. Treat the expansion as

irreversible and the gases formed as perfect.

- ☒ -21.3 kJ
- ☐ -39.1 kJ
- ☐ -47.3 kJ
- ☐ -52.8 kJ

✓ **Correct**

The work done on the system when it expands against constant pressure

is $W_{on} = -p\Delta V$. The decomposition of 1 mol of

solid NH_4Cl yields 1 mol of NH_3 and 1 mol of HCl or 2 mol of gas in total. Assuming the

volume of the solid to be negligible, the volume of gas released

$\Delta V = nRT/p$ and thus $W_{on} = -p \times nRT/p = -nRT = -2 \text{ mol} \times 8.314 \text{ J K}^{-1} \text{ mol}^{-1} \times 1280 \text{ K} = -21284 \text{ J}$ or -21.3 kJ .

6. The molar heat capacity of solid aluminium is $24.4 \text{ J K}^{-1} \text{ mol}^{-1}$ at 25°C . What is the change in internal energy when 1 mol of solid aluminium is heated from a temperature of 20°C to 30°C ?

- ☐ 102 J
☐ 128 J
☐ 153 J
☒ 244 J



Correct

$C_V = q_V/\Delta T = \Delta U/\Delta T$ and thus $\Delta U = C_V\Delta T = nC_{V,m}\Delta T$. For solids C_V and

C_p are virtually identical so we need not worry about the

distinction between them. If we assume that the heat capacity does

not vary over the temperature range then $\Delta U = 1 \text{ mol} \times 24.4 \text{ J K}^{-1} \text{ mol}^{-1} \times 10 \text{ K} = 244 \text{ J}$.

7. In the calibration step of a thermochemistry experiment, a current of 124 mA, from a 24.0 V source was allowed to flow through the electrical heater for 219 s and was found to result in an increase in the temperature of the calorimeter and its contents of $+1.39 \text{ K}$. Given that the energy supplied by an electrical circuit is the voltage multiplied by the current, multiplied by the time, what is the heat capacity of the calorimeter and its contents?

- ☐ 194 J K^{-1}
☐ 322 J K^{-1}
☒ 469 J K^{-1}
☐ 731 J K^{-1}



Correct

$C = q/\Delta T$. But $q = VIt$ thus $C = VIt/\Delta T = 24.0 \text{ V} \times 124 \times 10^{-3} \text{ A} \times 219 \text{ s} / 1.39 \text{ K} = 469 \text{ J K}^{-1}$.

8. The constant pressure molar heat capacity, $C_{p,m}$, of methane gas, CH_4 , is $35.31 \text{ J K}^{-1} \text{ mol}^{-1}$ at temperatures close to 298 K . Calculate the enthalpy change when 1.6 kg of methane gas is heated from a temperature of 280 K to 320 K .

- ☐ 103 kJ
☐ 119 kJ
☐ 132 kJ
☒ 141 kJ

✓ **Correct**

Assuming the heat capacity is constant over the temperature range, the

change in enthalpy on heating is $\Delta H = C_p \Delta T = n C_{p,m} \Delta T = (1600 \text{ g} / 16 \text{ g mol}^{-1}) \times 35.31 \text{ J K}^{-1} \text{ mol}^{-1} \times 40 \text{ K} = 141,240 \text{ J}$ or 141 kJ .

9. The constant pressure molar heat capacity of argon, $C_{p,m}$, is $20.79 \text{ J K}^{-1} \text{ mol}^{-1}$ at 298 K . What will be the value of the constant volume molar heat capacity of argon, $C_{V,m}$, at this temperature?

- ☒ $12.48 \text{ J K}^{-1} \text{ mol}^{-1}$
☐ $16.53 \text{ J K}^{-1} \text{ mol}^{-1}$
☐ $21.79 \text{ J K}^{-1} \text{ mol}^{-1}$
☐ $29.10 \text{ J K}^{-1} \text{ mol}^{-1}$

✓ **Correct**

Assuming ideal gas behaviour $C_{p,m} = C_{V,m} + R$ and thus

$C_{V,m} = C_{p,m} - R = 20.79 \text{ J K}^{-1} \text{ mol}^{-1} - 8.314 \text{ J K}^{-1} \text{ mol}^{-1} = 12.48 \text{ J K}^{-1} \text{ mol}^{-1}$. This relationship holds only for ideal gases. In

reality the difference will not be exactly $8.314 \text{ J K}^{-1} \text{ mol}^{-1}$.

10. The constant pressure molar heat capacity, $C_{p,m}$, of nitrogen gas, N_2 , is $29.125 \text{ J K}^{-1} \text{ mol}^{-1}$ at 298 K. Calculate the change in the internal energy when 20 mol of nitrogen gas at 298 K is heated so that its temperature increases by 15.0°C . You may assume constant heat capacity over the temperature range.

- ☐ 2.05 kJ
- ☐ 4.17 kJ
- ☒ 6.24 kJ
- ☐ 8.93 kJ



Correct

$\Delta U = q_V = C_V \Delta T = nC_{v,m} \Delta T$ but as in

Question 9, assuming ideal gas behaviour, $C_{V,m} = C_{p,m} - R$,

and thus $\Delta U = n(C_{p,m} - R) \Delta T = 20 \text{ mol} \times (29.125 - 8.314) \text{ J K}^{-1} \text{ mol}^{-1} \times 15 \text{ K} = 6243 \text{ J}$ or 6.24 kJ.