



Instructor Solutions Manual to Accompany Atkins' Physical Chemistry

ELEVENTH EDITION

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Numerical solutions to the problems

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Preface

This document is a compilation of the numerical solutions to the (b) *Exercises* and the even-numbered *Discussion questions* and *Problems* from the 11th edition of *Atkins' Physical Chemistry*. Where a problem requests the derivation of a result or expression, and provided that expression is not too complex, we have also included such results.

Errors and omissions

In such a complex undertaking some errors will no doubt have crept in, despite the authors' best efforts. Readers who identify any errors or omissions are invited to pass them on to us by email to pchem@ch.cam.ac.uk.

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1 The properties of gases

1A The perfect gas

E1A.1(b) 0.222 atm 1.03×10^5 Pa

E1A.2(b) no 10.4 bar

E1A.3(b) 1.07 bar 803 Torr

E1A.4(b) 120 kPa

E1A.5(b) $1.66... \times 10^5$ mol 2.67×10^3 kg.

E1A.6(b) P_4 .

E1A.7(b) 2.7 kg

E1A.8(b) 28.2 kPa 3.14 dm^3

E1A.9(b) $0.0164 \text{ kg mol}^{-1}$

E1A.10(b) $\theta = -270^\circ \text{C}$

E1A.11(b) $x_{\text{H}_2} = \frac{3}{8}$ $x_{\text{N}_2} = \frac{5}{8}$ $p_{\text{H}_2} = 1.5 \times 10^5 \text{ Pa}$ $p_{\text{N}_2} = 2.5 \times 10^5 \text{ Pa}$ $p_{\text{tot}} = 4.0 \times 10^5 \text{ Pa}$

PIA.2 -233°N .

PIA.4 -273.96°C

PIA.6 102 g mol^{-1}

PIA.8 $p_{\text{tot}} = 1.69 \times 10^5 \text{ Pa}$ $p_{\text{N}_2} = 0.338 \times 10^5 \text{ Pa}$ $p_{\text{NH}_3} = 1.35 \times 10^5$

PIA.10 $n_{\text{O}_3, 250 \text{ DU}} = 1.12 \times 10^{-3} \text{ mol}$ $n_{\text{O}_3, 100 \text{ DU}} = 4.46 \times 10^{-4} \text{ mol}$ $c_{\text{O}_3, 250 \text{ DU}} = 2.79 \times 10^{-9} \text{ mol dm}^{-3}$ $c_{\text{O}_3, 100 \text{ DU}} = 1.12 \times 10^{-9} \text{ mol dm}^{-3}$

PIA.12 $4.6 \times 10^3 \text{ mol}$ $1.3 \times 10^2 \text{ kg}$ $1.2 \times 10^2 \text{ kg}$

PIA.14 51 km 0.0030 atm

1B The kinetic model

E1B.1(b) 7.08

E1B.2(b) $v_{\text{rms}, \text{CO}_2} = 408 \text{ m s}^{-1}$ $v_{\text{rms}, \text{He}} = 1.35 \text{ km s}^{-1}$

E1B.3(b) 0.0107

E1B.4(b) 650 m s^{-1}

E1B.5(b) $v_{\text{mp}} = 1.56 \times 10^3 \text{ m s}^{-1}$ $v_{\text{mean}} = 1.75 \times 10^3 \text{ m s}^{-1}$ $v_{\text{rel}} = 2.48 \times 10^3 \text{ m s}^{-1}$

E1B.6(b) $6.2 \times 10^9 \text{ s}^{-1}$

E1B.7(b) 475 m s^{-1} $6.30 \times 10^4 \text{ m}$ $1.07 \times 10^{-2} \text{ s}^{-1}$

E1B.8(b) $3.4 \times 10^6 \text{ Pa}$

E1B.9(b) $5.8 \times 10^{-7} \text{ m} = 0.58 \text{ }\mu\text{m}$

PIB.2 $f(v) dv = \left(\frac{m}{kT}\right) v e^{-mv^2/2kT}$ $\langle v \rangle = \left(\frac{\pi kT}{2m}\right)^{1/2}$

PIB.4 39% 61% 47% greater than 53% less than

PIB.6 $\langle v^n \rangle^{1/n} = \frac{2^{1/n}}{\pi^{1/2n}} \left(\frac{2RT}{M}\right)^{\frac{1}{2}} \left(\left[\frac{1}{2}(n+1)\right]!\right)^{1/n}$ for odd n $\langle v^n \rangle^{1/n} = \left(\frac{RT}{M}\right)^{1/2} [(n+1)!!]^{1/n}$ for even n

$$\text{P1B.10 } v_{\max} = \left(\frac{2RT}{M} \right)^{1/2}$$

1C Real gases

$$\text{E1C.1(b) } 0.99 \text{ atm} \quad 1.9 \times 10^2 \text{ atm}$$

$$\text{E1C.2(b) } a = 0.134 \text{ kg m}^5 \text{ s}^{-2} \text{ mol}^{-2} \quad b = 4.36 \times 10^{-5} \text{ m}^3 \text{ mol}^{-1}$$

$$\text{E1C.3(b) } 1.12 \quad 2.7 \text{ dm}^3 \text{ mol}^{-1}$$

$$\text{E1C.4(b) } V_{\text{m}} = 0.124 \text{ dm}^3 \text{ mol}^{-1}, \quad V_{\text{m}} = 0.112 \text{ dm}^3 \text{ mol}^{-1}$$

$$\text{E1C.5(b) } 8.7 \text{ cm}^3 \quad -0.15 \text{ dm}^3 \text{ mol}^{-1}$$

$$\text{E1C.6(b) } 4.28 \text{ atm dm}^6 \text{ mol}^{-2} \quad 0.0546 \text{ dm}^3 \text{ mol}^{-1} \quad 176 \text{ pm}$$

$$\text{E1C.7(b) } 1.26 \times 10^3 \text{ K} \quad 163 \text{ pm}$$

$$\text{E1C.8(b) } 6.5 \text{ atm} \quad 1.5 \times 10^3 \text{ K} \quad 2.2 \text{ atm} \quad 7.2 \times 10^2 \text{ K} \quad 1.4 \text{ atm} \quad 3.6 \times 10^2 \text{ K}$$

$$\text{E1C.9(b) } 1.3 \times 10^{-4} \text{ m}^3 \text{ mol}^{-1} \quad 0.67$$

$$\text{P1C.2 } 12.5 \text{ dm}^3 \text{ mol}^{-1} \quad 12.3 \text{ dm}^3 \text{ mol}^{-1}$$

$$\text{P1C.4 } 0.94 \text{ dm}^3 \text{ mol}^{-1} \quad 2.7 \text{ dm}^3 \text{ mol}^{-1}$$

$$\text{P1C.6 } -0.082\%$$

$$\text{P1C.8 } T_{\text{c}} = (8/3)p_{\text{c}}V_{\text{c}}/R \quad 208 \text{ K} \quad 174 \text{ pm}$$

$$\text{P1C.12 } V_{\text{m}} = 3b \quad T = 8a/27Rb \quad p = a/27b^2$$

$$\text{P1C.14 } B = B'RT \quad C = R^2T^2[(B')^2 + C']$$

$$\text{P1C.16 } \left(\frac{\partial V_{\text{m}}}{\partial T} \right)_p = \frac{RV_{\text{m}} + b}{2pV_{\text{m}} - RT}$$

$$\text{P1C.20 } 53.42 \text{ atm} \quad 494.7 \text{ K}$$

$$\text{I1.2 } 0.25 \text{ J cm}^{-3}$$

2 Internal energy

2A Internal energy

E2A.1(b) 7.4 kJ mol^{-1} 7.4 kJ mol^{-1} 7.4 kJ mol^{-1}

E2A.3(b) -281 J

E2A.4(b) $q = +2.68 \text{ kJ}$ $w = -6.3 \text{ kJ}$ $\Delta U = 0$ $q = +3.41 \text{ kJ}$ $w = -3.41 \text{ kJ}$ $\Delta U = 0$
 $q = 0$ $w = 0$ $\Delta U = 0$

E2A.5(b) $p_f = 143 \text{ kPa}$ $\Delta U = +3.28 \text{ kJ}$ $q = +3.28 \text{ kJ}$ $w = 0$

E2A.6(b) -19 J -53 J

P2A.2 0

P2A.4 $9.1 \times 10^{-16} \text{ N}$

P2A.8 -8.9 kJ

2B Enthalpy

E2B.1(b) $C_{p,m} = 53 \text{ J K}^{-1} \text{ mol}^{-1}$ $C_{V,m} = 44 \text{ J K}^{-1} \text{ mol}^{-1}$

E2B.2(b) $\Delta H_m = \Delta U_m$

E2B.3(b) $q_p = +11.6 \text{ kJ}$ $w = -624 \text{ J}$ $\Delta U = +11.0 \text{ kJ}$ $\Delta H = +11.6 \text{ kJ}$ $q_V = +11.0 \text{ kJ}$
 $w = 0$ $\Delta U = +11.0 \text{ kJ}$ $\Delta H = +11.6 \text{ kJ}$

E2B.4(b) $q_p = \Delta H = +2.0 \text{ kJ}$ $\Delta U = +1.6 \text{ kJ}$

P2B.2 $6.1 \times 10^2 \text{ s}$

P2B.4 $a = 28.8 \text{ J K}^{-1} \text{ mol}^{-1}$ $b = 2.79 \times 10^{-2} \text{ J K}^{-2} \text{ mol}^{-1}$ $c = -1.51 \times 10^5 \text{ J K mol}^{-1}$
 $\alpha = 24.6 \text{ J K}^{-1} \text{ mol}^{-1}$ $\beta = 3.83 \times 10^{-2} \text{ J K}^{-2} \text{ mol}^{-1}$ $\gamma = -6.58 \times 10^{-6} \text{ J K}^{-3} \text{ mol}^{-1}$

2C Thermochemistry

E2C.1(b) $q = \Delta H = +76.1 \text{ kJ}$ $w = -3.78 \text{ kJ}$ $\Delta U = +72.3 \text{ kJ}$

E2C.2(b) $-3054 \text{ kJ mol}^{-1}$

E2C.3(b) -55 kJ mol^{-1}

E2C.4(b) $5.09 \times 10^{-2} \text{ kJ K}^{-1}$ $+79.6 \text{ K}$

E2C.5(b) $\Delta_r H^\circ(3) = -589.56 \text{ kJ mol}^{-1}$ $\Delta_r U^\circ = -582 \text{ kJ mol}^{-1}$ $\Delta_f H^\circ(\text{HCl}, \text{g}) = +26.48 \text{ kJ mol}^{-1}$
 $\Delta_f H^\circ(\text{H}_2\text{O}, \text{g}) = -241.82 \text{ kJ mol}^{-1}$

E2C.6(b) $-760.3 \text{ kJ mol}^{-1}$

E2C.7(b) $\Delta_r H^\circ(298 \text{ K}) = -174.83 \text{ kJ mol}^{-1}$ $\Delta_r U^\circ(298 \text{ K}) = -172 \text{ kJ mol}^{-1}$ $\Delta_r H^\circ(478 \text{ K}) = -179 \text{ kJ mol}^{-1}$

E2C.8(b) $-53.7 \text{ kJ mol}^{-1}$

P2C.2 $3.4 \times 10^4 \text{ kJ}$

P2C.4 $-1152.4 \text{ kJ mol}^{-1}$