Question 1

Food companies use nitrogen gas, N_2, to fill in the empty space in food packaging.

Example of Nitrogen Gas Used in Food Packaging

What property of nitrogen gas makes it a good choice for use in food packaging?

A) Nitrogen gas acts as a catalyst and prolongs the shelf-life of foods.

B) Nitrogen gas reacts with the oxygen gas in air and prevents food spoilage.

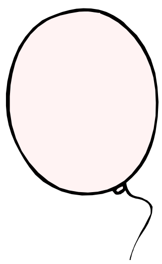
C) Nitrogen gas reacts with the water vapour in air and prevents food spoilage.

D) Nitrogen gas is chemically inactive due to its triple bond and prolongs the shelf-life of foods.

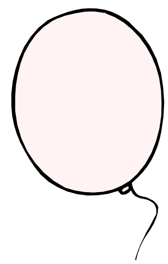
Question 2

Two identical balloons were filled to the same pressure, temperature and volume with different gases.

Balloon A
Nitrogen Gas, N_2



Balloon B
Carbon Dioxide Gas, CO_2



Which of the following statements about the gases in the two balloons is TRUE?

A) Balloon A contains more moles of gas than Balloon B and the mass of the gas in Balloon A is equal to the mass of the gas in Balloon B.

B) Balloon A contains fewer moles of gas than Balloon B and the mass of the gas in Balloon A is less than the mass of the gas in Balloon B.

C) Balloon A and Balloon B contain the same number of moles of gas and the mass of the gas in Balloon A is less than the mass of the gas in Balloon B.

D) Balloon A and Balloon B contain the same number of moles of gas and the mass of the gas in Balloon A is equal to the mass of the gas in Balloon B.

Question 3

Helium gas is used to fill balloons because it is inert and has a low density.

At a winter carnival a 255 L helium tank was used to fill 250 balloons. Once filled, each balloon contained 17.3 L of helium gas at STP.

What was the initial pressure of the full helium tank?
Assume the temperature remains constant, no gas is lost, and that the tank is completely emptied.

A) 1.01×10^2 kPa

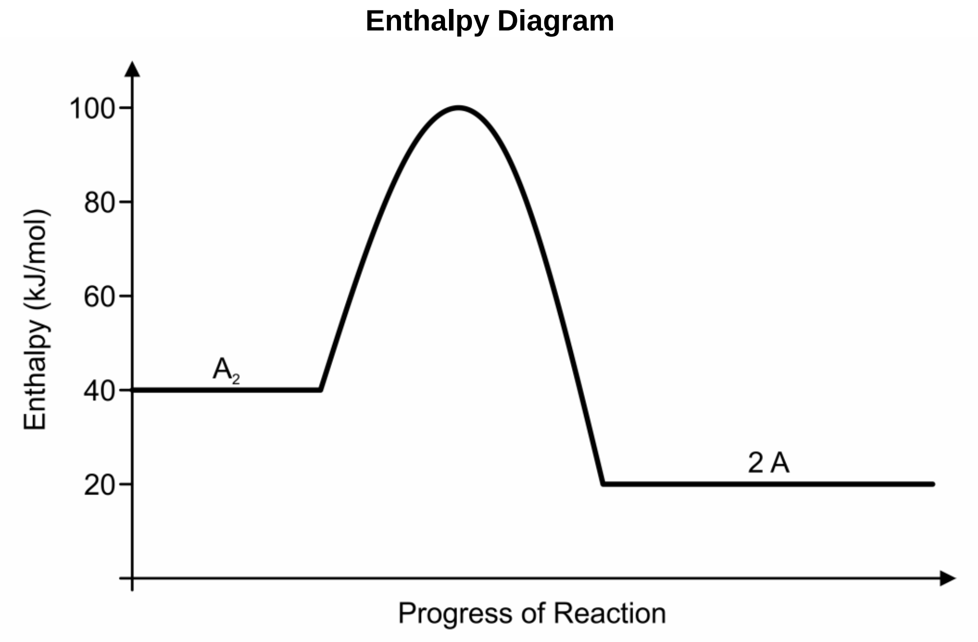
B) 1.72×10^3 kPa

C) 1.90×10^3 kPa

D) 3.70×10^5 kPa

Question 4

The enthalpy diagram for the decomposition of a molecule is shown below:



Which of the equations below correctly represents the decomposition of the molecule shown in the diagram?

A) $A_2 \rightarrow 2\ A + 20\ kJ$

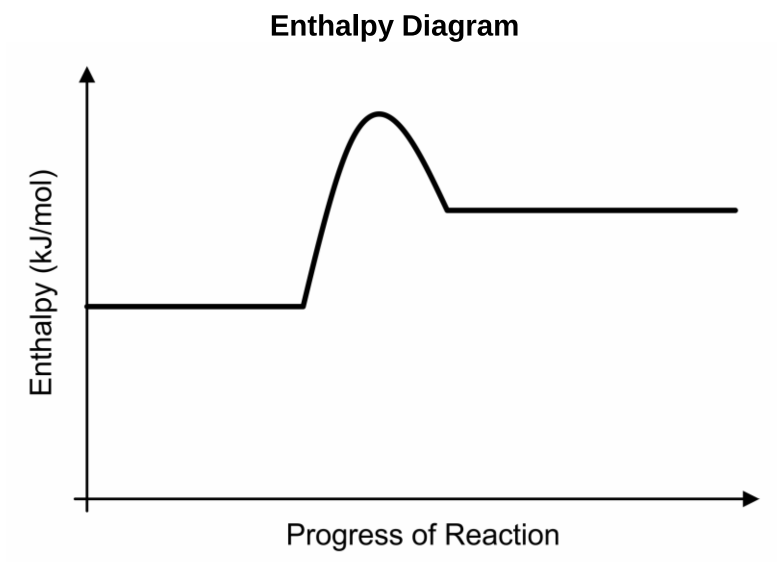
B) $A_2 \rightarrow 2\ A + 60\ kJ$

C) $A_2 + 20\ kJ \rightarrow 2\ A$

D) $A_2 + 60\ kJ \rightarrow 2\ A$

Question 5

The enthalpy diagram for the dissolution of a salt in water is shown below:



Which of the following statements about the dissolution of this salt is TRUE?

A) The system lost energy and the ΔH of the dissolution is positive.

B) The system lost energy and the ΔH of the dissolution is negative.

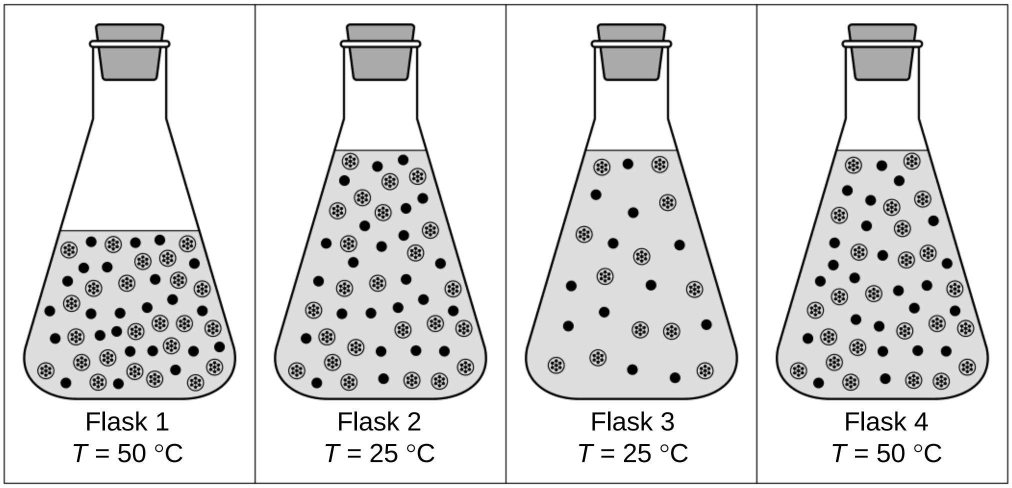
C) The system gained energy and the ΔH of the dissolution is positive.

D) The system gained energy and the ΔH of the dissolution is negative.

Question 6

The same chemical reaction is carried out in solution in four separate flasks under different conditions.

The diagrams below illustrate the reactant molecules in each flask before the reaction begins.



Which of the following combinations lists the reaction in each flask in order, from slowest to fastest?

A) Flask 1, Flask 4, Flask 2, Flask 3

B) Flask 2, Flask 3, Flask 1, Flask 4

C) Flask 3, Flask 2, Flask 1, Flask 4

D) Flask 3, Flask 2, Flask 4, Flask 1

Question 7

At a given temperature, the rate law for an elementary reaction is:

$$r = k\,[C]^2\,[D]$$

Which of the elementary reactions below is represented by the rate law above?

A) $C_2D_{(s)} \rightarrow 2\,C_{(g)} + D_{(g)}$

B) $2\,C_{(g)} + D_{(g)} \rightarrow C_2D_{(g)}$

C) $C_{2(g)} + D_{(g)} \rightarrow C_2D_{(g)}$

D) $C_2D_{(s)} \rightarrow C_{2(g)} + D_{(g)}$

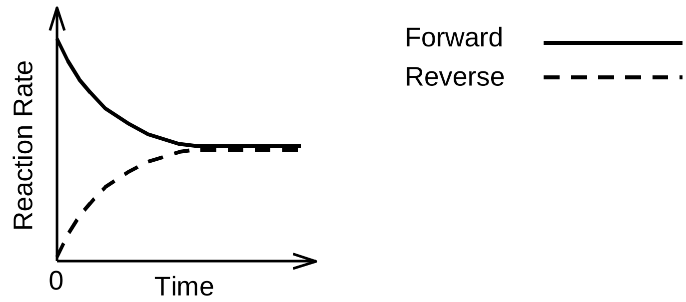
Question 8

Steam, $H_2O_{(g)}$, and carbon monoxide, $CO_{(g)}$, are placed in a closed vessel at a high temperature and allowed to reach equilibrium.

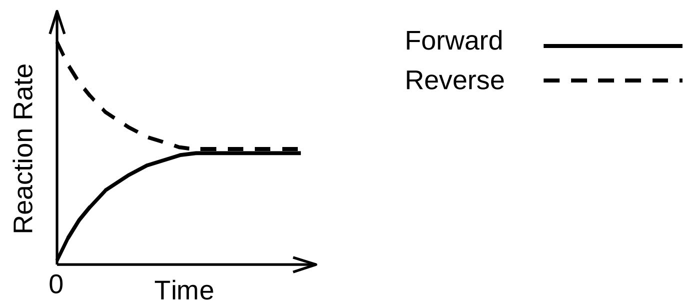
$$H_2O_{(g)} + CO_{(g)} \leftrightharpoons H_{2(g)} + CO_{2(g)}$$

Which of the graphs below best represents the forward and reverse reaction rates from the start of the reaction until it reaches equilibrium?

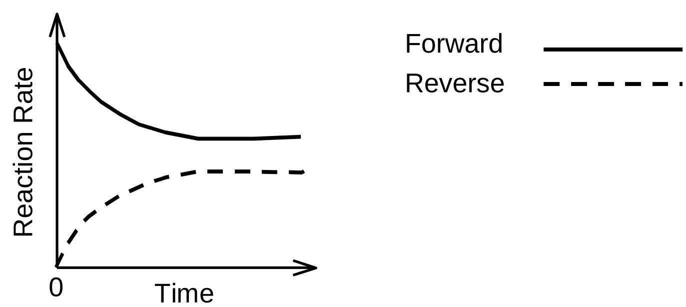
A)



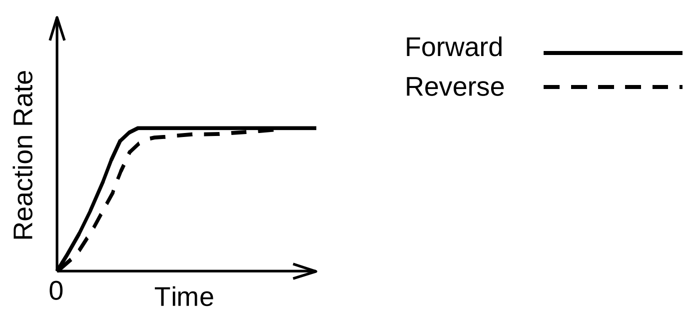
B)



C)



D)



Question 9

The red blood cells in the human body pick up oxygen from the lungs and deliver it to the body's cells. This process is possible because the hemoglobin molecule on red blood cells combines with oxygen molecules to form oxyhemoglobin.

This reaction at equilibrium is shown below:

$$\underset{\text{Hemoglobin}}{Hb_{(aq)}} + 4\,O_{2(g)} \rightleftharpoons \underset{\text{Oxyhemoglobin}}{Hb(O_2)_{4(aq)}}$$

Four conditions are listed below.

1. Inhaling pure oxygen from a pressurized tank.

2. A person hiking at a high altitude, where the air has a lower concentration of oxygen.

3. A person with Thalassemia, a genetic disorder that results in the reduction in the amount of functional hemoglobin.

4. A person born and raised at a high altitude, resulting in the production of more hemoglobin in the blood than a person born and raised at a low altitude.

Which of the conditions described above would lead to the reaction shifting to the left?

A) 1 and 3

B) 1 and 4

C) 2 and 3

D) 2 and 4

Question 10

Several different acids contribute to the formation of acid rain.

The table below describes five of these acids.

Acids that Contribute to Acid Rain

Acid	**Formula**	**pH**	**K_a at 25 °C**
Carbonic Acid	H_2CO_3	5.3	4.4×10^{-7}
Nitric Acid	HNO_3	6.0	2.4×10^{1}
Sulfuric Acid	H_2SO_4	5.5	1.0×10^{3}
Sulfurous Acid	H_2SO_3	5.2	1.3×10^{-2}

Which are the strongest and weakest acids?

A) Strongest: Sulfurous Acid — Weakest: Nitric Acid

B) Strongest: Nitric Acid — Weakest: Sulfurous Acid

C) Strongest: Carbonic Acid — Weakest: Sulfuric Acid

D) Strongest: Sulfuric Acid — Weakest: Carbonic Acid

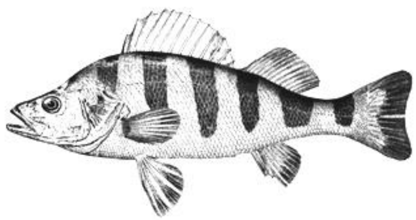
Part B ***Constructed-Response Questions***

Questions 11 to 25

Answer all questions in the ***Answer Booklet***.

Question 11

Swim bladders keep fish buoyant. Perch are a type of fish which have a swim bladder that inflates and deflates when gases move in and out of the swim bladder. In addition, as the perch swims deeper in the water, the water pressure decreases the size of its bladder.



Using the <u>Kinetic Molecular Theory</u>, explain the following observations:

a) Gases can diffuse from the swim bladder to the blood.

b) The swim bladder decreases in size when the water pressure increases.

Question 12

Hannah has been asked to collect the carbon dioxide gas, CO_2, formed during the following reaction:

$$CaCO_{3(s)} + 2\ HCl_{(aq)} \rightarrow CaCl_{2(aq)} + CO_{2(g)} + H_2O_{(l)}$$

To initiate the reaction she used 50.0 mL of a 3.0 M hydrogen chloride, HCl, solution and sufficient calcium carbonate, $CaCO_3$.

What volume of carbon dioxide gas did Hannah collect at 25.0 °C and 90.0 kPa?

Question 13

A company manufactures a gas mixture of argon, Ar, and hydrogen, H_2, for use during the welding process. The argon-hydrogen mixture is sold in 50.0 L cylinders.

The mixture is prepared by injecting hydrogen gas into a 50.0 L cylinder containing pure argon gas at a pressure of 13 500 kPa at 15.0 °C until the pressure of 1.5×10^4 kPa is reached. The temperature remains constant during the process.

The hydrogen gas for the mixture is produced by the electrolysis of water, as shown by the chemical equation below.

$$2\ H_2O_{(l)} \rightarrow O_{2(g)} + 2\ H_{2(g)}$$

What is the minimum mass of water required to produce enough hydrogen gas for one cylinder of the gas mixture?
Assume no gas is lost.

Question 14

While Chris Hadfield was preparing for a space walk, he also carried out an experiment for science students. He filled a balloon with 250.0 mL of pure oxygen gas inside the International Space Station, where it was kept at SATP.

Before going out, he brought the balloon to the equipment lock, where the pressure was reduced to 70.3 kPa and the temperature was 32.0 °C.

What was the volume of the balloon when it was in the equipment lock?
Assume no gas escapes from the balloon.
Significant figures will be evaluated in this question.

Question 15

Ellie and Samantha used a calorimeter to determine the molar heat of dissolution of the salt lithium chloride, LiCl.

$$LiCl_{(s)} \rightarrow Li^{+}_{(aq)} + Cl^{-}_{(aq)}$$

They dissolved 2.5 g of the salt in 1.0 L of water, and the temperature of the water increased by 0.50 °C.

Determine the molar heat of dissolution of lithium chloride.
Significant figures will be evaluated in this question.

Question 16

The formation of a molecule, A_2B_2, at STP from its constituent gases is:

$$A_2B + \tfrac{1}{2}\, B_2 \rightarrow A_2B_2 \quad \Delta H = -240 \text{ kJ/mol}$$

This reaction has an activation energy of 135 kJ/mol.

The potential energy of the products is 100 kJ/mol.

a) **Draw a complete enthalpy diagram for the <u>decomposition</u> of A_2B_2.**
Label the heat of reaction, ΔH, and the activation energy, E_a, for the reaction.

b) **Determine the value of ΔH and E_a of the decomposition reaction.**

Question 17

The term "thermal cracking" refers to a method used to break down larger fuel molecular structures into simpler molecules for different uses.

The chemical equation for the "cracking" of hexanol, $C_6H_{13}OH_{(l)}$, is:

$$C_6H_{13}OH_{(l)} + 6\ H_{2(g)} \rightarrow 6\ CH_{4(g)} + H_2O_{(g)}$$

The thermochemical equations for several other reactions at SATP are shown below.

Enthalpy Values at SATP

Formation reaction	**Enthalpy value**
$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$	$\Delta H = -393$ kJ/mol
$C_{(s)} + 2\ H_{2(g)} \rightarrow CH_{4(g)}$	$\Delta H = -76$ kJ/mol
$6\ C_{(s)} + 7\ H_{2(g)} + \frac{1}{2}\ O_{2(g)} \rightarrow C_6H_{13}OH_{(l)}$	$\Delta H = -377$ kJ/mol
$H_{2(g)} + \frac{1}{2}\ O_{2(g)} \rightarrow H_2O_{(g)}$	$\Delta H = -242$ kJ/mol
$H_{2(g)} + \frac{1}{2}\ O_{2(g)} \rightarrow H_2O_{(l)}$	$\Delta H = -285$ kJ/mol

Determine the heat of reaction, ΔH, for the "cracking" of hexanol.

Question 18

Due to diminishing supplies and concern for the environment, replacements for fossil fuels, for example biofuels, are increasing in use.

Olive oil is being tested for use as a source of biofuel. The olive oil biofuel releases 19.7 kJ/g of energy. A sample of the biofuel with a mass of 0.287 g is burned in a bomb calorimeter containing 250.0 mL of water at an initial temperature of 23.0 °C.

What is the final temperature of the water?
Assume no loss of heat and complete combustion.

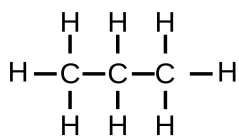
Question 19

Propane, C_3H_8, is a hydrocarbon that is commonly used as a fuel for cooking in gas ranges and outdoor barbeques.

The balanced chemical equation for the combustion of propane is:

$$C_3H_{8(g)} + 5\ O_{2(g)} \rightarrow 3\ CO_{2(g)} + 4\ H_2O_{(g)}$$

The structure of C_3H_8 is:



A table of bond enthalpies is shown below.

Bond Enthalpies

Bond	**Enthalpy (kJ/mol)**
H–H	436
H–O	460
C–H	413
C–C	347
C=O	745
C–O	358
O=O	498

Determine the molar heat for the combustion of propane using bond enthalpies.

Question 20

Ammonium sulphate, $(NH_4)_2SO_4$, is used as a fertilizer to treat soil with a high alkalinity. It can be produced through the following reaction:

$$2\ NH_{3(g)} + H_2SO_{4(aq)} \rightarrow (NH_4)_2SO_{4(aq)}$$

The rate law for this reaction at a certain temperature can be expressed as:

$$r = k\ [NH_3]^2$$

In order to increase the rate of production of ammonium sulphate, a chemist doubles the mass of the ammonia, NH_3, used and reduces the volume of the reaction vessel by half.

Determine the factor by which the reaction rate increases under the new conditions.

Question 21

Gallium arsenide, GaAs, is used in the manufacturing of semi-conductors, light-emitting diodes, LEDs, and solar cells.

The reaction for the production of gallium arsenide at equilibrium is:

$$2\ Ga_{(g)} + 2\ AsCl_{3(g)} \rightleftharpoons 2\ GaAs_{(s)} + 3\ Cl_{2(g)} + 87.7\ kJ$$

List four modifications of the reaction conditions which would result in manufacturers being able to produce more gallium arsenide in their factories. Explain your answer.

Question 22

When a 0.40 M ammonia solution, $NH_{3(aq)}$, dissolves in water it forms an ammonium hydroxide solution, $NH_4OH_{(aq)}$.

$$NH_{3(aq)} + H_2O_{(l)} \rightleftharpoons NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$$

At 25.0 °C, the pH of the equilibrium mixture is 11.4.

Determine the base dissociation constant, K_b, of ammonia at 25.0 ºC.

Question 23

Fluoride is found in many commercial products, such as toothpaste. The mineral fluorite, composed of calcium fluoride, CaF_2, is an important source of fluoride.

The equilibrium equation for the dissociation of calcium fluoride is:

$$CaF_{2(s)} \rightleftharpoons Ca^{2+}{}_{(aq)} + 2\ F^-{}_{(aq)}$$

The solubility constant, K_{sp}, at 25 °C of calcium fluoride is 3.45×10^{-11}.

Calculate the fluoride ion concentration in a saturated solution of calcium fluoride ion at 25 °C.

Question 24

Gastric juice, secreted by cells lining the stomach, promotes the breakdown of proteins. On average, gastric juice has a pH value between 1 and 3. When food arrives in the stomach, the pH of the gastric juice rises.

a) **If the pH of the gastric juice is 2.4 before the food arrives in the stomach, what is the pOH and [H^+] at that time?**

b) **After the arrival of food, the pH rises to 4.6. What is the [OH^-] of the gastric juice after the arrival of food?**

Question 25

At a given temperature, hydrogen gas, H_2, and iodine gas, I_2, are placed in a sealed 2 L container.

After some time, the following equilibrium is reached:

$$H_{2(g)} + I_{2(g)} + 53\text{ kJ} \rightleftharpoons 2\,HI_{(g)}$$

Once equilibrium is achieved, there are 10 moles of $H_{2(g)}$, 4 moles of $I_{2(g)}$ and 12 moles of hydrogen iodide gas, HI.

a) **Calculate the value of the equilibrium constant, K_c.**

b) **What will happen to the value of the equilibrium constant if the temperature of the reaction vessel is decreased? Explain your answer.**

Appendix 1

PERIODIC TABLE OF THE ELEMENTS

Key

Element symbol — Atomic number — Atomic mass

1 **H** 1.01

	I A **1**	II A **2**	III B **3**	IV B **4**	V B **5**	VI B **6**	VII B **7**	VIII B **8**	VIII B **9**	VIII B **10**	I B **11**	II B **12**	III A **13**	IV A **14**	V A **15**	VI A **16**	VII A **17**	VIII A **18**
1	1 **H** hydrogen 1.01																	2 **He** helium 4.00
2	3 **Li** lithium 6.94	4 **Be** beryllium 9.01											5 **B** boron 10.81	6 **C** carbon 12.01	7 **N** nitrogen 14.01	8 **O** oxygen 16.00	9 **F** fluorine 19.00	10 **Ne** neon 20.18
3	11 **Na** sodium 22.99	12 **Mg** magnesium 24.31											13 **Al** aluminum 26.98	14 **Si** silicon 28.09	15 **P** phosphorus 30.97	16 **S** sulphur 32.07	17 **Cl** chlorine 35.45	18 **Ar** argon 39.95
4	19 **K** potassium 39.10	20 **Ca** calcium 40.08	21 **Sc** scandium 44.96	22 **Ti** titanium 47.90	23 **V** vanadium 50.94	24 **Cr** chromium 52.00	25 **Mn** manganese 54.94	26 **Fe** iron 55.85	27 **Co** cobalt 58.93	28 **Ni** nickel 58.71	29 **Cu** copper 63.55	30 **Zn** zinc 65.39	31 **Ga** gallium 69.72	32 **Ge** germanium 72.59	33 **As** arsenic 74.92	34 **Se** selenium 78.96	35 **Br** bromine 79.90	36 **Kr** krypton 83.80
5	37 **Rb** rubidium 85.47	38 **Sr** strontium 87.62	39 **Y** yttrium 88.91	40 **Zr** zirconium 91.22	41 **Nb** niobium 92.91	42 **Mo** molybdenum 95.94	43 Tc technetium 98.91	44 **Ru** ruthenium 101.07	45 **Rh** rhodium 102.91	46 **Pd** palladium 106.40	47 **Ag** silver 107.87	48 **Cd** cadmium 112.41	49 **In** indium 114.82	50 **Sn** tin 118.71	51 **Sb** antimony 121.75	52 **Te** tellurium 127.60	53 **I** iodine 126.90	54 **Xe** xenon 131.30
6	55 **Cs** caesium 132.91	56 **Ba** barium 137.33	57-71 lanthanoids	72 **Hf** hafnium 178.49	73 **Ta** tantalum 180.95	74 **W** tungsten 183.85	75 **Re** rhenium 186.21	76 **Os** osmium 190.20	77 **Ir** iridium 192.22	78 **Pt** platinum 195.09	79 **Au** gold 196.97	80 **Hg** mercury 200.59	81 **Tl** thallium 204.37	82 **Pb** lead 207.20	83 **Bi** bismuth 208.98	84 **Po** polonium (209)	85 **At** astatine (210)	86 **Rn** radon (222)
7	87 **Fr** francium (223)	88 **Ra** radium (226)	89-103 actinoids	104 Rf rutherfordium (267)	105 Db dubnium (268)	106 Sg seaborgium (271)	107 Bh bohrium (272)	108 Hs hassium (270)	109 Mt meitnerium (276)	110 Ds darmstadtium (281)	111 Rg roentgenium (280)	112 Cn copernicium (285)	113 Uut ununtrium (284)	114 Fl flerovium (289)	115 Uup ununpentium (288)	116 Lv livermorium (293)	117 Uus ununseptium (292)	118 Uuo ununoctium (294)

6	57 **La** lanthanum 138.91	58 **Ce** cerium 140.12	59 **Pr** praseodymium 140.91	60 **Nd** neodymium 144.24	61 Pm promethium (145)	62 **Sm** samarium 150.36	63 **Eu** europium 151.96	64 **Gd** gadolinium 157.25	65 **Tb** terbium 158.93	66 **Dy** dysprosium 162.50	67 **Ho** holmium 164.93	68 **Er** erbium 167.26	69 **Tm** thulium 168.93	70 **Yb** ytterbium 173.05	71 **Lu** lutetium 174.97
7	89 Ac actinium (227)	90 Th thorium 232.04	91 Pa protactinium 231.04	92 U uranium 238.03	93 Np neptunium (237)	94 Pu plutonium (244)	95 Am americium (243)	96 Cm curium (247)	97 Bk berkelium (247)	98 Cf californium (251)	99 Es einsteinium (252)	100 Fm fermium (257)	101 Md mendelevium (258)	102 No nobelium (259)	103 Lr lawrencium (262)

Appendix 2

FORMULAS

$$Q = mc\Delta T$$

$$PV = n\,RT$$

$$\frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2}$$

$$P_T = P_A + P_B + P_C + \ldots$$

$$P_A = P_T\,\frac{n_A}{n_T}$$

Appendix 3

PHYSICAL CONSTANTS

SYMBOL	NAME	VALUE
c_{H_2O}	Specific heat capacity of water	4190 J/(kg•°C) or 4.19 J/(g•°C)
ρ_{H_2O}	Density of water	1.00 g/mL
R	Molar gas constant	8.31 kPa•L/(mol•K)
SATP	Standard ambient temperature and pressure	Temperature: 25.0 °C
		Pressure: 101.3 kPa
STP	Standard temperature and pressure	Temperature: 0 °C
		Pressure: 101.3 kPa