School student competition 2010
Riga – Vilnius – Tallinn – Helsinki – Vasterås – St. Petersburg

Solutions ENGLISH VERSION

Please check for errors official solution first, before start comparing them with student solutions!

Form 10

Problem 1

Write molecular equations for reactions to show how to realize such chemical transformations: (8 + 0.5*4 points = 10 points)

$$CaCO_3 \xrightarrow{1} Ca(HCO_3)_2 \xrightarrow{2} CaCl_2 \xrightarrow{3} Ca(OH)_2 \xrightarrow{4} (CH_3COO)_2Ca \xrightarrow{5} CaSO_4 \xrightarrow{6} \to SO_3 \xrightarrow{7} H_2SO_4 \xrightarrow{8} CuSO_4$$

0.5 p. for correct products and reactants (incorrect formulas = 0 p.) + 0.5 points for balancing equations

1) $CaCO_3 + H_2O + CO_2 \rightarrow Ca(HCO_3)_2$ (accept H_2CO_3 and other acids, then corresponding salt is formed)
2) $Ca(HCO_3)_2 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2\uparrow$ (does not accept H_2CO_3)
3) $CaCl_2 + 2NaOH \rightarrow Ca(OH)_2\downarrow + 2NaCl$ (accept other alkali and electrolysis of $CaCl_2$ solution)
4) $Ca(OH)_2 + 2CH_3COOH \rightarrow (CH_3COO)_2Ca + 2H_2O$
5) $(CH_3COO)_2Ca + H_2SO_4 \rightarrow CaSO_4\downarrow + 2CH_3COOH$
6) $CaSO_4 \xrightarrow{t^o} CaO + SO_3\uparrow$ (no penalty if no temperature mentioned)
7) $SO_3 + H_2O \rightarrow H_2SO_4$
8) $Cu + 2H_2SO_4 \rightarrow CuSO_4 + SO_2\uparrow + 2H_2O$ (do not accept formation of H_2)

Example. State number of reaction were strong acid is formed: 7.
State number of reaction, which is naturally occurred in nature: 1.
State number of reaction for which requires heating: 6.
State number of reaction, where white precipitate is obtained: 3. or 5. (max points even if one answer)
State number of reaction, where weak acid is formed: 5.

Problem 2

a. $w(NaCl) = \dfrac{m(NaCl)}{m(solution)} = \dfrac{m(NaCl)}{m(NaCl) + m(water)} = \dfrac{16}{16+100} = 13.8\%$ (2 points)

b. x – mass of salt you have to add, g

$0.20 = \dfrac{16+x}{116+x}$ $\quad 16 + x = 0{,}20 \cdot (116 + x) = 23.2 + 0.20x \quad 0.8x = 7.2 \quad x = 9\,g$ (3 points)

c. $w(saturated) = \dfrac{40}{40+100} = \dfrac{40}{140} = 28.6\%$

Solution 2.b. w = 20% <w(saturated) $\Rightarrow$ solution in 2.b is unsaturated (1 + 1 point = 2 points)

d. You have to evaporate water. x – mass of water you have to evaporate, g

$w = w(saturated) = \dfrac{16+9}{125-x} = 0.2857 \quad 125 - x = \dfrac{25}{0.2857} = 87.5 \quad x = 37.5g$ (2 points)

Mass of solution after evaporation 87.5 g. (1 point)

Problem 3

General formula for metal oxides: M_2O_x, where x – valence of metal.

Oxygen content = $w(O) = \frac{M(O) \cdot x}{M(M_2O_x)} = \frac{16x}{2M + 16x} = 0.4$

$16x = 0.4 \cdot (2M + 16x) = 0.8M + 6.4x$

$0.8M = 9.6$

$M = 12x$

If x = …. , then relative molecular mass of M = ….

1	12	no such metal
2	24	Magnesium
3	36	no such metal
4	48	titanium
5 etc.	… no such metals	

Answer: A – magnesium, B – titanium (A – smaller atomic mass)

(Solution where student guess one or both metals and then check for oxygen content is also acceptable.)

4 points for each metal

Magnesium can be used in production of titanium:

$2Mg + TiCl_4 \xrightarrow{T} Ti + 2MgCl_2$ (no penalty for missing temperature sign) 2 points

Problem 4

Reaction equation: NaOH + HCl→NaCl + H_2O (1 point)

1st titration is rough error and it should be excluded from further calculations (2 points; also in case if student ignores this result without any comment)

$V(average, HCl) = \frac{10.58 + 10.56 + 10.54}{3} = 10.56\,mL$ (0.5 points)

Density of HCl solution = 1.00 + 0.100/2 = 1.05 g/mL (0.5 points)

Mass of HCl solution = 1.05 · 10.56 = 11.088 g (0.5 points; no penalties for incorrect number of significant figures, significant figures are graded only in answer).

Mass of HCl = 0.100 · 11.088 = 1.1088 g (0.5 points)

Amount of HCl $n = \frac{m}{M} = \frac{1.1088}{36.5} = 0.0304\,mol$ (1 point)

n(HCl) = n(NaOH) = 0.03040 mol (1 point)

m(NaOH) = n· M = 0.0304 · 40 = 1.215 g (1 point)

$w = \frac{m(NaOH)}{m(solution)} = \frac{1.215}{10.0} = 12.15\% = 12.2\%$ (1 point; 3 sig. figures, if different then 0.5 points)

More suitable indicator would be methyl orange because its color change would be sharper. It would be difficult to determine whether solution is pink or colorless. (1 point; no explanation is required from students).

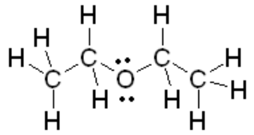
Problem 5

a. Hydrocarbons are compounds **1 and 2**. Contains only hydrogen and carbon. (1 point; if one correct 0.5 points; if one correct and one incorrect 0 points; if both correct and one incorrect – 0.5 points; other cases 0 points)

b. Hydrogen bond formation – compounds **5 and 6**. Hydrogen bonds between hydroxyl group and water molecules. (1 point; other cases same as 5.a)

c. Molecule contains 14 sigma (single) bonds and no pi bonds. (0.5 + 0.5 points)

3.



(0.5 (correct number of atoms) + 0.5 (correct bonds) + 1 (lone pairs on O))

d. Order: 2. < 1. =(<;>) 3. < 4. < 5. < 6. (correct situation at each "<" sign – 0.5 points; + 0.5 points for correct overall order, total max 3 points)

Exact boiling points: 2. – 28^{o}C; 1. – 36^{o}C; 3. – 35^{o}C; 4. –79^{o}C; 5. – 118^{o}C; 6. – 138.5^{o}C. Source: www.wikipedia.org .

e. Compound 3:

$C_4H_{10}O + 6O_2 \rightarrow 4CO_2 + 5H_2O$ (complete combustion)

$C_4H_{10}O + 4O_2 \rightarrow 4CO + 5H_2O$ (incomplete combustion)

Compound 4:

$2C_4H_9Cl + 12.5O_2 \rightarrow 8CO_2 + 9H_2O + Cl_2$ (complete combustion)

$2C_4H_9Cl + 8.5O_2 \rightarrow 8CO + 9H_2O + Cl_2$ (incomplete combustion)

each complete and balanced equation 0.5 points, total 2 points (accept partial coefficients)

Form 11

Problem 1

$NO_3^- \xrightarrow{1} Cu(OH)_2 \xrightarrow{2} [Cu(NH_3)_4]^{2+} \xrightarrow{3} SO_4^{2-} \xrightarrow{4} BaSO_4 \xrightarrow{5} SO_3 \xrightarrow{6} H^+ \xrightarrow{7}$
$\rightarrow H_2S \xrightarrow{8} S^{2-} \xrightarrow{9} ZnS \xrightarrow{10} SO_2 \xrightarrow{11} SO_3^{2-} \xrightarrow{12} CaSO_3 \xrightarrow{13} Ca^{2+} \xrightarrow{14} OH^-$

Reaction equations:

1) $Cu(NO_3)_2 + 2NaOH$ (or other soluble hydroxide) $\rightarrow 2NaNO_3 + Cu(OH)_2\downarrow$ (0.5 p.)
2) $Cu(OH)_2 + 4NH_3 \rightarrow [Cu(NH_3)_4](OH)_2$(1 p.)
3) $[Cu(NH_3)_4](OH)_2 + 3H_2SO_4 \rightarrow CuSO_4 + 2(NH_4)_2SO_4 + 2H_2O$ (0.5 p.)
4) $CuSO_4$ (or ammonium sulfate) + $BaCl_2$ (or nitrate) $\rightarrow BaSO_4\downarrow + CuCl_2$(0.5 p.)
5) $BaSO_4 \xrightarrow{T} BaO + SO_3$ (no penalty for missing temperature) (0.5 p.)
6) $SO_3 + H_2O \rightarrow H_2SO_4$(0.5 p.)
7) $H_2SO_4 + Na_2S \rightarrow Na_2SO_4 + H_2S$ (0.5 p.)
8) H2S + 2NaOH (or other soluble hydroxide) $\rightarrow$ Na2S + 2H2O (0.5 p.)
9) $Na_2S + ZnSO_4$ (or other soluble salt) $\rightarrow ZnS\downarrow + Na_2SO_4$(0.5 p.)
10) $2ZnS + 3O_2 \rightarrow 2ZnO + 2SO_2$(1 p.)
11) $SO_2 + 2NaOH$ (other hydroxide or water) $\rightarrow Na_2SO_3 + H_2O$ (0.5 p.)
12) $Na_2SO_3 + CaCl_2$ (or other soluble salt) $\rightarrow CaSO_3\downarrow + 2NaCl$ (0.5 p.)
13) $CaSO_3 + 2HCl$ (or other strong acid with soluble Ca(II) salt) $\rightarrow CaCl_2 + SO_2\uparrow + H_2O$ (0.5 p.)
14) $CaCl_2 + 2H_2O \xrightarrow{electrolysis} Ca(OH)_2 + Cl_2\uparrow + H_2\uparrow$ (1.5 p.)

Ionic equations:

$Cu^{2+} + 2NO_3^- + 2Na^+ + 2OH^- \rightarrow 2Na^+ + 2NO_3^- + Cu(OH)_2\downarrow$ (0.5 p.)
$Cu^{2+} + 2OH^- \rightarrow Cu(OH)_2\downarrow$ (0.5 p.)

Problem 2

* I. $2Na + 2H_2O \rightarrow 2NaOH + H_2\uparrow$ (0.5 points)
* II. $MnO_2 + 4HCl \rightarrow Cl_2 + MnCl_2 + 2H_2O$ (0.5 points)
III. $MgCl_2 + 2NaOH \rightarrow Mg(OH)_2 + 2NaCl$ (0.5 points)
IV. $Zn(OH)_2 + 2NaOH \rightarrow Na_2ZnO_2 + 2H_2O$ (1 point, students have to correct formula to Na_2ZnO_2)
* V. $Zn + 2NaOH + 2H_2O \rightarrow Na_2[Zn(OH)_4] + H_2\uparrow$ (2 points, students have to add H_2O and H_2)

Oxidation-reduction reactions are marked with "*". (0.5 points)
Reaction I. –oxidizing agent H or H_2O, reducing agent – Na
Reaction II. – oxidizing agent MnO_2, Mn(IV), Mn, reducing agent – HCl, Cl, Cl^-.
Reaction V. – oxidizing agent H, H2O, reducing agent – Zn. (for each reaction 0.5 p. for reducing agent and 0.5 p. for reducing agent, all together 3 points).

Reaction I:
oxidation: Na – e- $\rightarrow Na^+$
reduction: $2H_2O$ + 2e- $\rightarrow H_2$ + 2OH- (eachhalfreaction 1 point; alsoacceptablefor II. and V. equation)
Donotaccept 2H+ + 2e- $\rightarrow H_2$

Problem 3

A – Cu, **B** – Fe, **C** – SO_2, **D** – H_2 (0.5· 4 = 2 points)

Reaction equations:

$Cu + 2H_2SO_4(conc.) \rightarrow CuSO_4 + SO_2\uparrow + 2H_2O$ (1 p.)

$Fe + H_2SO_4(dil.) \rightarrow FeSO_4 + H_2\uparrow$ (0.5 p.)

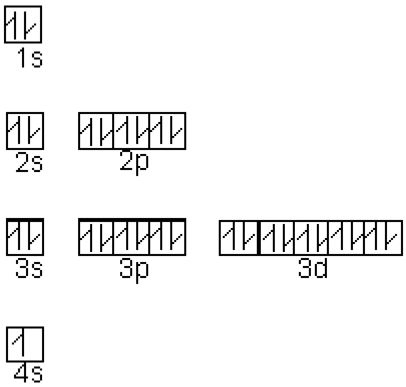
$Fe + CuSO_4 \rightarrow Cu\downarrow + FeSO_4$ (0.5 p.)

$FeSO_4 + 2NaOH \rightarrow Na_2SO_4 + Fe(OH)_2\downarrow$ (0.5 p.)

$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3$ (1 p.)

Cu atom:

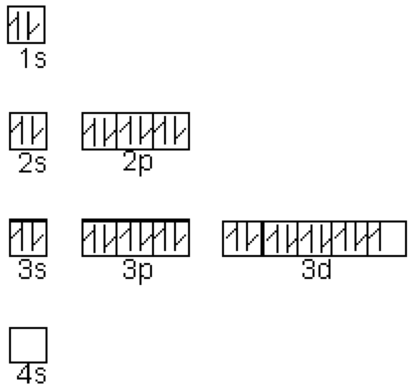
Electron arrangement $)_2)_8)_{18})_1$



2 points (1 + 1)

Cu^{2+} ion:

Electron arrangement $)_2)_8)_{17}$



1.5 points (0.5 + 1)

Problem 4

a. $H_2O + CaCO_3 \cdot MgCO_3 + 2CO_2 \rightarrow Ca^{2+} + Mg^{2+} + 4HCO_3^-$ (ionic and net ionic equation)3 points

b. $Ca^{2+} + Mg^{2+} + 4HCO_3^- \rightarrow CaCO_3\downarrow + MgCO_3\downarrow$ (1 point) (ionic and net ionic aquation)

c. $3Ca^{2+}$(or Mg^{2+}) $+ 2PO_4^{3-} \rightarrow Ca_3(PO_4)_2\downarrow$ (1 points)

$3Ca^{2+} + 6HCO_3^- + 6Na^+ + 2PO_4^{3-} \rightarrow Ca_3(PO_4)_2\downarrow$ (1 points)

d. $n(M^{2+}) = n(EDTA) = CV = 0.00700 \cdot 10.57 \cdot 10^{-3} = 0.07399$ mol per 50 mL of tap water (2 points)

$n(M^{2+}) = \frac{n}{V} = \frac{0.07399 \cdot 10^{-3}}{0.05} = 1.48 \cdot 10^{-3} mol/L$ (2 points)

Problem 5

1. $2AgBr \rightarrow 2Ag + Br_2$ (1 point)
2. $Ag^+ + e \rightarrow Ag^0$ 2

   $2Br^- \rightarrow 2e + Br_2^0$ 1

   $2Ag^+ + 2e \rightarrow 2Ag^0$ Ox.agent (2 points)

   $2Br^- \rightarrow 2e + Br_2^0$ Red.Agent (2 points)
3. No,AgBr is not soluble in water. Sodium thiosulfate make AgBr soluble in complex form.

   $AgBr(s) + 2S_2O_3^{2-}(aq) \rightarrow Ag(S_2O_3)_2^{3-}(aq) + Br^-(aq)$ (2 points)
4. The entire photographic process is repeated a second time. Light is passed through the negative image onto special photographic paper that is coated with the same kind gelatin-AgBr emulsion used on the original film. (3 points)

Form 12

Problem1

Filled table:

Compound	Cl_2	C_3H_8	C_2H_4	C_3H_4	Ca	CaO	$CaCO_3$
CH_4	+	-	-	-	-	-	-
Na	+	-	-	-	-	-	-
HCl	-	-	+	+	+	+	+
H_2O	+	-	+	+	+	+	-
H_2	+	-	+	+	+	-	-

Each correctly filled row – 1 point, if one error then 0.5 points, other cases 0 points.

Reaction equations:

$Cl_2 + CH_4 \rightarrow CH_3Cl + HCl$

$2Na + Cl_2 \rightarrow 2NaCl$

$HCl + C_2H_4 \rightarrow C_2H_5Cl$
$2HCl + C_3H_4 \rightarrow C_3H_6Cl_2$ or $HCl + C_3H_4 \rightarrow C_3H_5Cl$
$Ca + 2HCl \rightarrow CaCl_2 + H_2$
$CaO + 2HCl \rightarrow CaCl_2 + H_2O$
$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$

$Cl_2 + H_2O \rightarrow HCl + HClO$ or $Cl_2 + H_2O \rightarrow 2HCl + ½O_2$
$H_2O + C_2H_4 \rightarrow C_2H_5OH$
$H2O + C_3H_4 \rightarrow CH_3COCH_3$
$Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$
$H_2O + CaO \rightarrow Ca(OH)_2$

$H_2 + Cl_2 \rightarrow 2HCl$
$H_2 + C_2H_4 \rightarrow C_2H_6$
$H_2 + C_3H_4 \rightarrow C_3H_6$ or $2H_2 + C_3H_4 \rightarrow C_3H_8$
$Ca + H_2 \rightarrow CaH_2$

Reaction equations corresponding to each row – 1 point. (one coefficient or one equation missing or more, 0.5 points (only for rows 3, 4 and 5), other cases – 0 points).

Problem2

Amount of gas in moles $n = \frac{V}{V_0} = \frac{22.4 \cdot 10^{-3}}{22.4} = 0.001 mol$

Molar mass of gas: $M = \frac{m}{n} = \frac{0.058}{0.001} = 58\, g/mol$

It corresponds to maximum 4 carbon atoms in molecule. Then number of hydrogens = 58 – 4*12 = 10, so formula of gas **C_4H_{10} – butane** (or isobutane).

It is alkane, so it does not react with bromine solution and potassium permanganate.

2 points for butane, 1 point for explanation

Complete combustion: $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$ (accept partial coefficients)

Incomplete combustion: $2C_4H_{10} + 9O_2 \rightarrow 8CO + 10H_2O$ (accept partial coefficients)

1 point for each equation; 0.5 points if wrong coefficient; wrong product – 0 points

$n(C_4H_{10})$ = 0.001 mol $\Rightarrow$ $n(CO_2)$ = 4 ·0.001 = 0.004 mol

$m(Ba(OH)_2)$ = 0.05 · 10 = 0.5 g

$$n(Ba(OH)_2) = \frac{m}{M} = \frac{0.5}{171} = 2.92 \cdot 10^{-3} mol$$

$CO_2 + Ba(OH)_2 \rightarrow BaCO_3\downarrow + H_2O$ (1)

0.004 mol … 0.00292 mol

So $n(BaCO_3)$ = 0.00292 mol

Then excess of carbon dioxide reacts with $BaCO_3$ and forms $Ba(HCO_3)_2$.

$BaCO_3 + CO_2 + H_2O \rightarrow Ba(HCO_3)_2$ (2)

$n(CO_2$ remaining after reaction (1)) = 0.004 – 0.00292 = 0.01076 mol

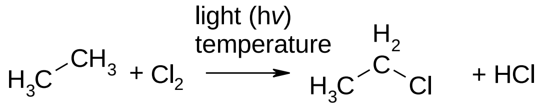
$n(BaCO_3$ remaining after reaction (2)) = 0.00292 - 0.01076 = 0.00185 mol

$m(BaCO_3)$ = n · M = 0.00185 · 197 = 0.364 ≈ 0.36 ≈ 0.4 g (accept all answers)

reaction equations – 2 points, calculations – 3 points, if does not take in account formation of hydrogen carbonate – 1 p. max (for reactions and calculations)

Problem 3

a.



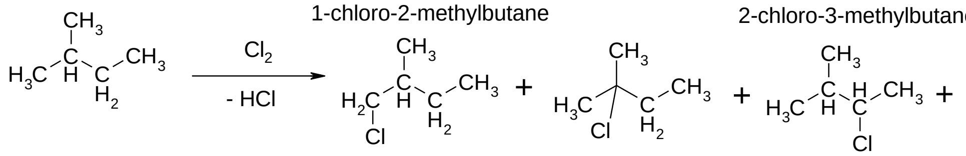
hydogen chloride
(does not accept hydrochloric acid)

1-chloroethane
(does not accept only chloroethane)

0.5 points – reactionequation; 0.5 points – reactionconditions; 0.5 p. eachname, total 2 points

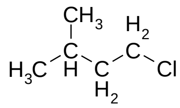
b.

1-chloro-2-methylbutane   2-chloro-3-methylbutane



I   2-chloro-2-methylbutane   III

II

IV 

1-chloro-3-methylbutane

0.5pointsforeach formula andname, total2points

c. relative rate of formation of selected compound = number of hydrogen atoms * relative speed

rate of formation of compound I = 6 * 1 = 6

rate of formation of compound II = 1 * 5 = 5

rate of formation of compound III = 2 * 3.8 = 7.6

rate of formation of compound I = 3 * 1 = 3

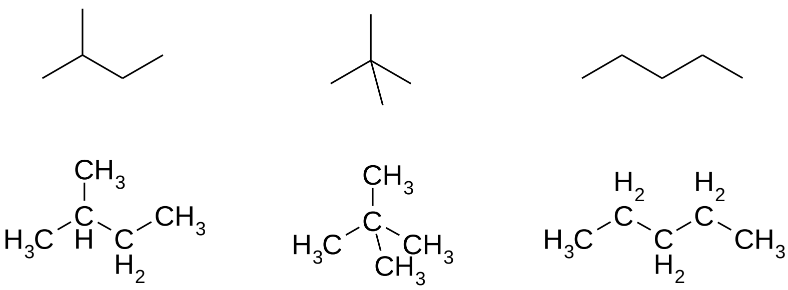
w(I) = $\frac{6}{6+5+7.6+3} = 0.28 = 28\%$

w(II) = $\frac{5}{21.6} = 23\%$ w(III) = 35%   w(IV) = 14%

for each mass fraction 1 point, max. 4 points

d. Isomers of 2-methylbutane:

2-methylbutane   2,2-dimethylpropane   pentane



e. Number of monochlorination products:

4   1   3

forcorrectalldataaboutoneisomer 0.5 points, about 2-methylbutane students have to answerthisforsecondtime

f. 2,2-dimethylpropane < 2-methylbutane < pentane (correct order 0.5 point; incorrect 0 points)

From Wikipedia exact temperatures: 2-methylbutane 27°C boiling point, 2,2-dimethylpentane –9.5°C, pentane – 36°C.

Problem 4

a. reactions for detection of listed ions:

$NH_4^+ + NaOH \rightarrow NH_3\uparrow + OH^-$ (1p.)

NO_2^- ..no specific reactions, Griess reaction – formation of azo compounds (no penalty for this)

$S^{2-} + 2HCl \rightarrow H_2S\uparrow + 2Cl-$ (1p.)

$P^{3-} + 3HCl \rightarrow PH_3\uparrow + 3Cl-$ (1p.)

Na^+ ..characterictic flame reaction, yellow color (1p.)

b. Explosive composition: $NaNO_3$, S, P. (2 p.; 1p. –nitrates; S, P compounds – 1 p.)

c. Explosion reaction:

$5NaNO_3 + P + 5S \rightarrow Na_3PO_4 + Na_2SO_3 + 2.5N_2\uparrow + 4SO_2\uparrow$

$10NaNO_3 + 2P + 10S \rightarrow 2Na_3PO_4 + 2Na_2SO_3 + 5N_2\uparrow + 8SO_2\uparrow$

$N^{+5} + 5e \rightarrow N^0$ * 4 + 1

$P^0 - 5e \rightarrow P^{+5}$

$S^0 - 4e \rightarrow S^{+4}$ * 5

Different versions of coefficients are acceptable, accept partial coefficients.

reaction equation 4 points (reasonable products and reactants 2p., 2p. – correct coefficients)

Problem 5

a. **A** – graphite, **B** – diamond (1 point)

b. Graphite:

Let's consider regular hexagon prism with a = 1.4 Å and h = 3.3 Å. It has 12 vertices with 12 carbon atoms. Each carbon atom is divided between 6 prisms. So each prism contains only 1/6 of carbon each atom.

Number of carbon atoms in prism = 1/6 * 12 = 2 atoms

$$m_0 = \frac{M}{N_A} = \frac{12}{6.02 \cdot 10^{23}} = 1.99 \cdot 10^{-23} g$$

V(prism) = S · h =

S ..regular hexagon can be divided into 6 regular triangles, square of each triangle is

S(triangle) = ½ · a^2· sin60^o = ½ · (1.4 ·10^{-8}) · 0.866 = 8.48 ·10^{-17} cm^2

S(hexagon) = 6 · 8.48 ·10^{-17}= 5.09 · 10^{-16} cm^2

V(prism) = 5.09 · 10^{-16}· 3.3 · 10^{-8} = 1.68 · 10^{-23} cm^3

density = $\frac{m}{V} = \frac{2 \cdot 1.99 \cdot 10^{-23}}{1.68 \cdot 10^{-23}} = 2.4$ g/cm^3 (2 points)

Diamond:

There are two isosceles triangles with bottom of half diagonal. One half of this triangle is right angled triangle with hypotenuseof 1.54Å.

sin(109.5/2) = $\frac{d/4}{1.54} = \sin(54.75) = 0.8166 \Rightarrow$ d = 5.0305 Å

diagonal d ofcubeface d = 5.0305 Å = a · $\sqrt{2}$

a = 3.55 Å = 3.55· 10^{-8} cm

V(cube) = 4.5· 10^{-23} cm^3

mass of cube? .. each cube contains 4 (in the middle) + ½ · 6 + 1/8 ·8 = 8 carbon atoms, so:

density = $\frac{m}{V} = \frac{8 \cdot 1.99 \cdot 10^{-23}}{4.5 \cdot 10^{-23}} = 3.5$ g/cm^3 (2 points)

c. Process is possible; at high pressure graphite (carbon powder) can be converted to diamonds. It is used in technique when producing "synthetic" diamonds. (1 point)

d. Molar heat of combustion:

Carbon powder:

$n = 1 mol$ … heat of combustion 393.5 kJ/mol = molar heat of combustion for carbon powder (1 point)

$$n = \frac{2.50}{12} = 0.208 mol$$

82,4 kJ corresponds to combustion of 0.2083 mol C

x kJ … 1 mol

x = $\frac{82.4 \cdot 1}{0.208} = 396$ kJ (0.5 points)

e. More heat are produced from combustion of diamond, so diamonds have higher energy than powdered carbon, so to change carbon powder to diamond you have to add energy (usually heat). So **reaction carbon powder → diamond is endothermic**. (1 point)

f. Opposite process, transformation of diamond to is possible heating diamonds at temperatures above 1000^{o}C (anaerobic conditions). (1 point)