Comments in italics are explanations, not part of the answer I was looking for.

Question 1 (24 points) **ANSWERS**

Benzoic acid, $C_7H_6O_2$ (s), burns in O_2(g), forming CO_2(g), and H_2O(ℓ).

a) (3) Balance the chemical reaction for the combustion reaction:

___1__ $C_7H_6O_2$ (s) + _15/2_ O_2 (g) → __7___ CO_2 (g) + ___3__ H_2O (ℓ)

or _2__ $C_7H_6O_2$ (s) + __15__ O_2 (g) → __14__ CO_2 (g) + __6__ H_2O (ℓ)

b) (4) A glass bulb is evacuated and weighed. Oxygen (O_2) gas is added, and the bulb reweighed. The empty bulb weighed 24.323 g, and the filled bulb 29.7920 g. How many moles of O_2(g) are present?

mass O_2(g) = 29.7920 – 24.3234 = 5.469 grams

molar mass O_2 = 2(15.9994 g/mole) = 31.9988 g/mole

moles O_2(g) = (5.469 g) / (31.9988 g/mole) = 0.170$\underline{9}$13 mole → $\underline{\text{0.1709 moles}}$ [4 s.f.]

c) (7) 2.53 grams of benzoic acid is added to the container. Which will be the limiting reagent in the explosion?

M = 7(12.011) +6(1.00794) + 2(15.9994) = 122.123 g/mole

n = w/M = (2.53 g)/(122.123 g/mole) = 0.020$\underline{7}$17 moles.

$\underline{\text{Method I}}$: Suppose benzoic was limiting:

From the reaction, (moles O_2 reacting)/(moles benzoic reacting) = 15/2,

so moles O_2 needed to react completely = (15/2)(0.020717) = 0.15$\underline{5}$376.

There is more than enough O_2, so the benzoic acid is limiting.

(if you assume instead that O_2 is limiting, you find there is insufficient benzoic acid)

$\underline{\text{Method II}}$: calculate moles of product CO_2 [or H_2O] that each would produce if limiting;

if benzoic limiting, moles CO_2 = 7 (moles benzoic acid) = 0.1450 moles CO_2

if O_2 limiting, moles CO_2 = (14/15) (moles O_2) = 0.159518 moles CO_2

Since benzoic acid produces less CO_2, it runs out first, so it is limiting.

If you calculated moles of a product produced by each (Method 2), and said benzoic acid was limiting without saying why, I deducted 2 points. You reasoning must be explicit!

d) (10) Based on the amounts given in parts b and c, how many moles each of the following are present after the reaction goes to completion?

moles $C_7H_6O_2$ (s) __none, limiting______ **moles CO_2(g)** __0.145____________

moles O_2(g) ____0.016________________ **moles H_2O(ℓ)** __0.0622 __________

Calculations: *use molar ratios from the balanced equation*

0.020$\underline{7}$17 moles benzoic acid reacts with excess O_2 forming

(14/2)(0.020$\underline{7}$17 moles) = 0.14$\underline{5}$0 moles CO_2 (as found in Method II above)

(6/2)(0.020$\underline{7}$17 moles) = 0.062150 → 0.0622 moles H_2O

Moles O_2 left = initial moles – moles reacting = 0.170913 – 0.155376 = 0.01$\underline{5}$537 moles left
use sig. fig. rules for addition and subtraction

Question 2 (20 points) **ANSWERS**

Agmatine is an intermediate in biosynthesis. A putative neurotransmitter, it is synthesized in the brain and stored in synaptic vesicles and released by membrane depolarization. Elemental analysis of agmatine gives the following percents by weight: C (46.1%), N (43.0%), and the rest H. What is the empirical formula of agmatine?

% by weight H (by difference) = 100 –46.1 –43.0 = 10.9

Consider a 100 gram sample of cadaverine. [← *say this!]* The %'s by weight become grams:

	w / M =	moles / smallest =	molar ratio → round*	integer ratio	× 4
C	46.1/ 12.011	= 3.838148 / 3.069959	= 1.250228 → 1.25	= 1 1/4	**5**
H	10.9/ 1.00794	= 10.81414 / 3.069959	= 3.522566 → 3.52	= 3 1/2	**14**
N	43.0/ 14.0067	= 3.069959 / 3.069959	= [1]	= [1]	**4**

so the empirical formula is $\mathbf{C_5H_{14}N_4}$ or $\mathbf{(C_5H_{14}N_4)_n}$

* *You must round to the correct number of significant figures immediately after finding the decimal molar ratios. Then the significant figure rule that says that the rightmost digit is uncertain allows you to decide what integer ratio is a possible equivalent. I deduct points for omitting correct rounding even if you got the correct ratio of integers, since you did not give me evidence that you have carefully taken significant figures into account in your reasoning.*

What about $C_{125}H_{352}N_{100}$? That *is* consistent with the data, so is hypothetically possible. But when doing empirical formula problems you must look for the smallest integer ratios that work. Since 3.52 and 3.50 agree to 3 sig. figs, a H:N ratio of 7/2 is a better answer than 352/100.

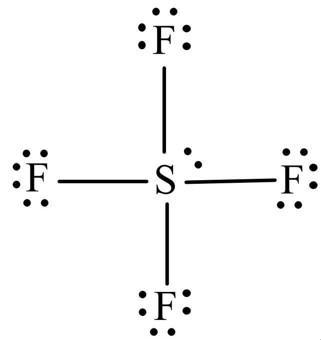
The actual molecule is $\mathbf{C_5H_{14}N_4}$ *: read about it in Wikipedia!*

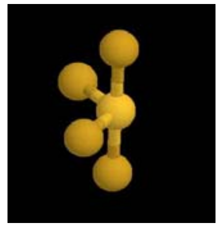
Question 3 (27 points) **ANSWERS**

Specify the total number of valence electrons and write the Lewis electron dot structure for each of the following. If there are multiple resonance structures, include them. Specify the *molecular* geometry, including the specified bond angle(s). Indicate whether the molecule is polar. Finally, supply the bond order:

a) SF_4 **# valence electrons: 6 + 4(7) =** 34

expanded shell:
5 bond groups (N=5),
framework is TBP
lone pair on equator

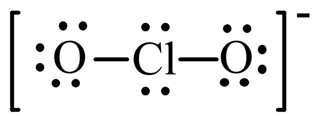




Molecular geometry: see-saw **F-S-F angles:** 90° , 120°, and 180°.

Polar? yes. **Bond order of S–F:** 1

b) chlorite: ClO_2^- **# valence electrons: 7 + 2(6) + 1 =** 20

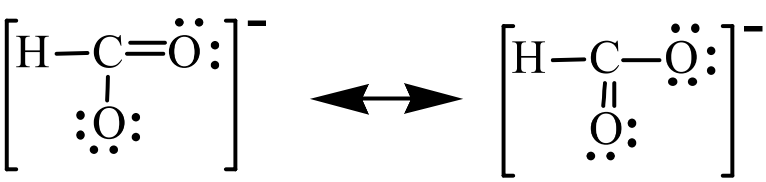


Molecular geometry: bent **O-Cl-O angle:** ~109° (or a little < 109°)

Polar? yes. **Bond order of O–Cl:** 1

c) formate ion, HCO_2^- (C in center) **# valence electrons: 1 + 4 + 2(6) + 1 =** 18

two resonance structures: equivalent, so properties, like bond order, are the average:



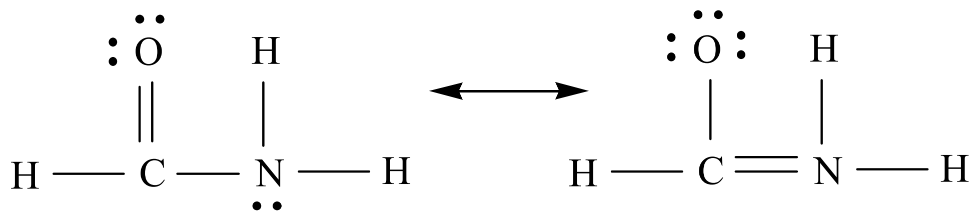
Molecular geometry: planar trigonal **O-C-O angle:** ~120°

Polar? yes **Bond order of C–O:** 1 ½ or 1.5

Question 4 (30 points) **ANSWERS**

The three parts of this question are not related to each other

A) (10 points) Resonance structures for formamide, $HCONH_2$, are



sum of formal charges must always equal molecular charge, here 0.

Assign formal charges to C, N, and O in both structures. What would you predict for the approximate bond order of the C–N bond? Why?

The left structure puts 0 formal charge on all three: C, N, and O. The second keeps C as zero, but puts –1 on O, and +1 on the N. The right structure is therefore much less favorable. The C–N bond is single on the left, double on the right. So the bond is closest to a single bond. *If you said it was the average, 1.5, you ignored the consequences of formal charge.*

B) (10 points) Iridium (Ir) has the largest density of any element. The popular website WebElements gives the density as 22650 kg/m^3. What is this in g/cm^3? Assuming that there is no empty space in the metal so that the atoms completely fill the volume, what is the volume of one atom of Ir? (a 2 significant figure estimate is sufficient).

(22650 kg/m^3)(1000 g/kg)(1 m/100 cm)^3 = 22650 x 10^3/10^6 = <u>22.650 g/cm^3</u> or <u>22.65 g/cm^3</u>

since water has a density of ~1 g/cm^3, this magnitude makes sense.
Numbers like 2.265 x 10^4 g/cm^3 are clearly wrong: one cc cannot weigh 23 kg!

To calculate the volume of one atom, start with any convenient amount, but specify your choice!

consider <u>one mole</u> of Ir: it weights 192.22 grams, so its volume is (192.22 g) / (22.650 g/cm^3) = 8.486 cm^3 (per mole), divide by N_A atoms/mole → <u>1.409 x 10^{-23} cm^3/atom</u>

or consider <u>one cm^3</u> Ir: it weighs 22.65 g → 22.65 g / 192.22 g/mole = 0.1178 moles (per cm^3)
multiply by N_A to get atoms: 7.096 x 10^{22} atoms (in one cm^3).
V/atom = (1.00 cm^3) / (7.096 x 10^{22} atoms) = <u>1.4 x 10^{-23} cm^3/atom</u>

C) (10 points) Two isotopes of Lithium are found in nature: ^{6}Li weighs 6.0151214 and ^{7}Li weighs 7.0160030. The atomic weight of Li is 6.941. What are the natural abundances of the two isotopes?

Since the atomic weight is much closer to the weight of ^{7}Li, most will be ^{7}Li.
(*2 points for observing this, even if you did not know how to calculate the result!*)

Let x = % ^{7}Li, then (100 –x) = % ^{6}Li (*ok to use fraction of one as variable instead*)

atomic weight = 6.941 = [(100–x)/100] (6.0151214) + (x/100) (7.0160030)

multiply by 100: 694.1 = 601.51214 + x (7.0160030–6.0151214)

x = (694.1– 601.51214) / (7.0160030–6.0151214) = 92.587 <u>92.6 % ^{7}Li</u> and <u>7.4% ^{6}Li</u>.

(three sig. figs in % ^{7}Li, due to the numerator, after subtraction. I allowed 3 or 4.)

Please come ask if you do not understand how to calculate a <u>weighted</u> average.

Question 5 (24 points) **ANSWERS**

A. (12) Complete the blank entries in the list of chemical formulas and compound names below. Indicate whether each compound is ionic or molecular by circling I or M.

CHEMICAL FORMULA	COMPOUND NAME	IONIC or MOLECULAR	
CF_4	carbon tetrafluoride	I	<u>M</u>

Next time I will deduct if you write "flouride": you are not baking a cake with flour.

$ZnCO_3$	zinc carbonate	<u>I</u>	M
$(NH_4)_2SO_3$	ammonium sulfite	<u>I</u>	M
N_2O_5	dinitrogen pentoxide	I	<u>M</u>
AlI_3	Aluminum iodide	<u>I</u>	M
PCl_5	Phosphorus pentachloride	I	<u>M</u>
K_3PO_4	Potassium phosphate	<u>I</u>	M
$Cu(OH)_3$	Copper (III) hydroxide	<u>I</u>	M

B) (12) Write balanced net ionic equations for the following observations:

a) A precipitate forms when lead (II) nitrate is mixed with sodium chloride.

We are starting with ions Pb^{2+}, NO_3^-, Na^+, and Cl^-. (Sodium and nitrate salts are all soluble.) Since sodium salts are soluble, the only possible precipitate would combine Pb^{2+} with Cl^-:

$$Pb^{2+}(aq) + 2\ Cl^-(aq) \rightarrow PbCl_2(s)$$

Since I did not explicitly say "solutions", I accepted solids as reagents.

b) Methylamine, $CH_3NH_2(aq)$, reacts with nitric acid.

methylamine is a base, a proton acceptor. (Amines are related to ammonia, and react in the same way: they can add protons.) Nitric acid is a strong acid, so it is present as ions.

$$CH_3NH_2(aq) + H^+(aq) \rightarrow CH_3NH_3^+(aq)$$

also ok: $$CH_3NH_2(aq) + H_3O^+(aq) \rightarrow CH_3NH_3^+(aq) + H_2O(\ell)$$

c) $CO_2(g)$ mixed with water makes an acidic solution.

This was shown in a lecture demonstration

$$CO_2(g) + H_2O(\ell) \rightarrow H_2CO_3(aq) \rightarrow H^+(aq) + HCO_3^-(aq)$$

it is ok to omit the intermediate, and simply write

$$CO_2(g) + H_2O(\ell) \rightarrow H^+(aq) + HCO_3^-(aq)$$

also ok is $$CO_2(g) + 2\ H_2O(\ell) \rightarrow H_3O^+(aq) + HCO_3^-(aq)$$

I also accepted $$CO_2(g) + H_2O(\ell) \rightarrow [\ H_2CO_3(aq) \rightarrow\ ]\ 2\ H^+(aq) + CO_3^{2-}(aq)$$

It is preferred to show the reaction forming only one H^+, not two, since H_2CO_3 is a weak acid, so even the first ionization reaction goes only a bit. We will explore this more later.