

Name: _____

Student number: _____

Chemistry 1A03

Test 1

October 12, 2007

McMaster University

VERSION 1 **Answers in blue & Full Solutions**

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Duration: 100 minutes

This test contains 20 numbered pages printed on both sides. There are **25** multiple-choice questions appearing on pages numbered 3 to 17. Page 18 is extra space for rough work. Page 19 includes some useful data and equations, and there is a periodic table on page 20. You may tear off the last page to view the periodic table and the data provided.

You must enter your name and student number on this question sheet, as well as on the answer sheet. Your invigilator will be checking your student card for identification. **You are responsible** for ensuring that your copy of the question paper is complete. Bring any discrepancy to the attention of your invigilator.

Questions 1 to 20 are each worth 2 marks, questions 21 – 25 are each worth 3 marks; the total marks available are 55. There is **no** additional penalty for incorrect answers.

BE SURE TO ENTER THE CORRECT VERSION OF YOUR TEST (shown near the top of page 1), IN THE SPACE PROVIDED ON THE ANSWER SHEET.

ANSWER ALL QUESTIONS ON THE ANSWER SHEET, IN PENCIL.

Instructions for entering multiple-choice answers are given on page 2.

SELECT ONE AND ONLY ONE ANSWER FOR EACH QUESTION from the answers (A) through (E). **No work written on the question sheets will be marked.** The question sheets may be collected and reviewed in cases of suspected academic dishonesty.

Academic dishonesty may include, among other actions, communication of any kind (verbal, visual, *etc.*) between students, sharing of materials between students, copying or looking at other students' work. If you have a problem please ask the invigilator to deal with it for you. Do not make contact with other students directly. Try to keep your eyes on your own paper – looking around the room may be interpreted as an attempt to copy.

Only Casio FX 991 electronic calculators may be used; but they must NOT be transferred between students. Use of periodic tables or any aids, other than those provided, is not allowed.

Questions 1-20 are worth two (2) marks each.

1. What are the total numbers of **neutrons, protons, and electrons**, respectively in the $^{37}\text{Cl}^-$ ion?

- (A) 37, 17, 18
(B) 20, 17, 16
(C) 17, 20, 18
(D) 20, 17, 18
(E) 18, 18, 17

Cl has atomic number (Z) 17 on the periodic table (see last page of your test). Thus it has 17 protons.
The ion shown here has a -1 charge, thus it has 17 electrons + 1 electron = 18 electrons.
The isotope shown has mass number (A) of 37. This means neutrons + protons = 37, and if there are 17 protons then there are 20 neutrons.

2. The material Styrofoam is made by blowing a gas into the polymer polystyrene; polystyrene is made by polymerizing the molecule styrene.
Styrene has the percent composition by mass of C 92.26% and H 7.74% What is the **empirical formula for styrene**?

- (A) CH_4
(B) CH_3
(C) C_2H_3
(D) CH_2
(E) **CH**

Assume a 100.0 g sample.
Then we have 92.26 g of C and 7.74 g of H.
Convert to moles:
 $\text{C} = 92.26 \text{ g} / 12.011 \text{ g/mol} = 7.68 \text{ mol C}$
 $\text{H} = 7.74 / 1.0079 \text{ g/mol} = 7.68 \text{ mol H}$
We have a formula of: $\text{C}_{7.68} \text{H}_{7.68}$
Divide each # of moles by the smallest value:
 $\text{C}_{7.68/7.68} \text{H}_{7.68/7.68} = \text{C}_1\text{H}_1$ is the empirical formula.

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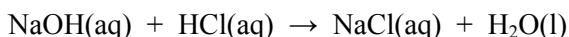
3. Choose the **incorrect name/formula combination**:

- (A) KH potassium hydride
(B) NaCO_3 sodium carbonate
(C) HCl hydrogen chloride
(D) $\text{Cu}_3(\text{PO}_4)_2$ copper (II) phosphate
(E) CaSO_3 calcium sulfite

The carbonate ion has the formula CO_3^{2-} , and so the correct formula for sodium carbonate is Na_2CO_3 .

4. Sometimes during titrations, when NaOH is added to a solution of HCl, the equivalence point is missed, evident by the bright pink colour of the phenolphthalein indicator (which turns pink in basic solutions). Under these circumstances, if the concentration of HCl was experimentally determined to be 0.1034 M with a 3.45 % error from the actual value. **Determine the actual concentration of HCl.**

- (A) 0.0946 M
(B) 0.100 M
(C) 0.103 M
(D) 0.107 M
(E) 0.112 M



If too many moles of NaOH are used, then we have overestimated the moles of HCl present, which means our calculated value of HCl concentration is too high.

The true value must therefore be less than 0.1034 M, so we can express our % error as -3.45 %.

From Lab 1, % error = $\frac{(\text{true value} - \text{obtained value})}{\text{true value}} \times 100\%$

Let x = true value, then

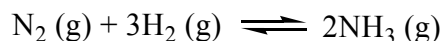
$$-3.45\% = \frac{(x - 0.1034 \text{ M})}{x} \times 100\%$$

Solving for x gives $x = 0.100 \text{ M}$

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5. The Haber-Bosch Process is one of the most important chemical reactions to produce large-scale amounts of ammonia used in the fertilizer industry. Determine the external **pressure (in atm)** required to contain 17.0 kg of NH_3 when the reaction is performed in a vessel that has a volume of 250.0 L with temperature set at 413°C .



- (A) 22800 atm
(B) 225 atm
(C) 135 atm
(D) 13.5 atm
(E) 1.00 atm

$$PV = nRT$$

$$\text{Isolate for pressure: } P = nRT/V$$

We require moles of NH_3 , the gas constant with appropriate units, and T in degrees Kelvin. These conversions are shown in the expression below:

$$P = \frac{[(17.0 \text{ kg} \times 10^3 \text{ g/kg}) / (17.034 \text{ g/mol})](0.08206 \text{ L atm/K mol})(413 + 273.15 \text{ K})}{250.0 \text{ L}}$$

$$P = 224.8 \text{ atm} = 225 \text{ atm}$$

6. Calculate the **frequency (in Hz)** of a photon which excites an electron from the $n = 2$ to the $n = 6$ shell of a “hot” hydrogen atom.

- (A) $6.549 \times 10^{32} \text{ Hz}$
(B) $5.843 \times 10^{16} \text{ Hz}$
(C) $7.308 \times 10^{14} \text{ Hz}$
(D) $2.82 \times 10^{-15} \text{ Hz}$
(E) $4.842 \times 10^{-19} \text{ Hz}$

Energy can be related to frequency, $E = h\nu$ and also to n levels, $E = R_H (1/n_i^2 - 1/n_f^2)$.

$$h\nu = R_H (1/n_i^2 - 1/n_f^2) \text{ where } n_i = 2 \text{ and } n_f = 6$$

$$\nu = R_H (1/n_i^2 - 1/n_f^2) / h$$

$$\nu = (2.178 \times 10^{-18} \text{ J}) (1/2^2 - 1/6^2) / 6.626 \times 10^{-34} \text{ Js}$$

$$\nu = 7.305 \times 10^{14} \text{ s}^{-1} \text{ or Hz}$$

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7. Choose the **INCORRECT** statement:

- (A) The emission spectrum of He atoms, when excited in an electrical discharge tube, is continuous in the visible range.
- (B) Experimental data regarding blackbody radiation is inconsistent with the theories of classical physics.
- (C) The work function of a metal represents the minimum energy a photon requires to eject an electron from that metal.
- (D) The deBroglie wavelength of a particle is inversely proportional to its mass.
- (E) The photoelectric effect experiment demonstrated that energy is quantized.

Statement A is False: Elements do not give continuous spectra, they give line, or discontinuous spectra, because energy changes in an atom are quantized.

(B) True. Classical physics could not explain why energy emission decreases at upper limits.

(C) True. This is the photoelectric effect.

(D) True. Refer to equation on the data page.

(E) True. Observed current is proportional to light intensity.

8. Calculate the **energy**, in **kJ/mol**, for the transition which gives rise to the 217 nm absorption process of lead ions (Pb^{2+}) in a flame atomic absorption spectrometer.

- (A) 9.15×10^{-19} kJ/mol
- (B) 807 kJ/mol
- (C) 2.82×10^{-18} kJ/mol
- (D) 43.6 kJ/mol
- (E) 551 kJ/mol

$$E = hc/\lambda$$

We must also pay attention to units. Use conversions for J and kJ, nm and m, and use Avogadro's number to scale up to the 1/mol unit.

$$E = \frac{(6.626 \times 10^{-34} \text{ Js})(10^{-3} \text{ kJ/J})(2.9979 \times 10^8 \text{ m/s})(6.022 \times 10^{23} \text{ 1/mol})}{(217 \text{ nm} \times 10^{-9} \text{ m/nm})}$$

$$E = 551.2 \text{ kJ/mol} = 551 \text{ kJ/mol}$$

9. Of the following, **which one corresponds to a pair of correct electron configurations** representing the **ground-state → excited state** of the given elements?

- (A) B: $1s^2 2s^2 2p^1$ → $1s^2 2s^2 2p^0$
 (B) Sn: $[Kr] 5s^2 4d^{10} 5p^2$ → $[Kr] 5s^2 4d^{10} 5p^3$
 (C) Rb: $[Kr] 5s^1$ → $[Kr] 4s^1$
 (D) Cl: $[Ne] 3s^2 3p^5$ → $[Ne] 3s^2 3p^4 4s^1$
 (E) O: $1s^2 2s^2 2p^5$ → $1s^2 2s^2 2p^4 3s^1$

- (A) Represents an ionization (electron lost)
 (B) Represents a reduction (electron gained).
 (C) Is an excited state → ground state transition.
 (D) Is correct.
 (E) Represents a ground state → excited state transition, but not for oxygen. Oxygen is $1s^2 2s^2 2p^4$.

10. Rank the following electromagnetic radiations **in order of INCREASING ENERGY** (from lowest energy to highest energy):

- (A) X-ray UVC UVA Visible Infra-Red
 (B) UVC UVA Visible Infra-Red X-ray
 (C) Visible X-ray UVA UVC Infra-Red
 (D) Infra-Red UVA Visible UVC X-ray
 (E) Infra-Red Visible UVA UVC X-ray

Refer to diagram of the electromagnetic spectrum, as well as class notes on UV radiation.

The visible region (red to blue) sits in between Infra-Red and UV (ultraviolet). The UV radiation is higher in energy than Infra-Red, and X-radiation sits at even higher energy, so we can say X-Ray > UV > Visible > Infra-Red.

UVA, UVB and UVC are all specific regions of the UV spectrum, with UVA at lowest energy (longest wavelength).

11. Which of the following ions **is/are not isoelectronic** with Ne?

- (i) Na^+
- (ii) Mg^{2+}
- (iii) S^{2-}
- (iv) F^-
- (v) Li^+

- (A) i
- (B) iv
- (C) i, iii
- (D) ii, v
- (E) iii, v

Isoelectronic means they have the same number of electrons.
Ne has configuration $1s^2 2s^2 2p^6$, so it has 10 electrons.
 F^- , Na^+ and Mg^{2+} are isoelectronic with Ne.
 Li^+ has only 2 electrons and is isoelectronic with He.
 S^{2-} has 18 electrons, and is isoelectronic with Ar.

12. Identify the reason that best explains why **Br^- is not used** as an additive in toothpaste to enhance the resistance to acid demineralization of hydroxyapatite, $\text{Ca}_5(\text{PO}_4)_3\text{OH}$?

- (A) Br^- has a smaller electron affinity than OH^-
- (B) Br^- has a lower ionization energy than Ca^{2+}
- (C) Br^- has a larger ionic radius than OH^-
- (D) Br^- has a smaller ionic radius than Ca^{2+}
- (E) Br^- has a higher electronegativity than OH^-

F^- is used as a toothpaste additive because it replaces OH^- ion lost from hydroxyapatite mineral in tooth enamel. Fluoride ion works well as a replacement for hydroxide ion because it bears the same charge, and is slightly smaller in size. It is also readily delivered to the tooth via toothpaste and drinking water.
 Br^- ion is much larger than F^- (and OH^-), and thus is not useful for the same purpose.

13. Identify the reason that **best explains why the second ionization energy (IE_2) for Ca is much lower than IE_2 of K**. Compared to K...

- (A) Ca has a larger atomic radius.
- (B) Ca has a smaller ionic radius.
- (C) Ca has a filled valence shell.
- (D) Ca has a filled 4s subshell.
- (E) Ca has a higher electron affinity.

We are being asked to compare the ionization of Ca^+ versus the ionization of K^+ .

Consider the electron configurations of these ions:

Ca^+ : $[Ar] 4s^1$

K^+ : $[Ar]$

K has already lost 1 electron, and as K^+ has a closed shell noble gas electron configuration. It would require a very large amount of energy to ionize a second electron.

Ca^+ has lost 1 electron, but can still lose another before it attains a closed shell noble gas electron configuration. It will require less energy to ionize a second electron from Ca^+ than from K^+ , as Ca had 2 valence electrons to begin with ($4s^2$), compared to only 1 valence electron for K ($4s^1$).

14. Which of the following gaseous pollutants could **not be detected** by electron capture detection:

- (i) CO
- (ii) $CFCl_3$
- (iii) CH_3Br
- (iv) CH_4
- (v) SF_6

- (A) v
- (B) ii, iii
- (C) ii, iii, v
- (D) ii, v
- (E) i, iv

Electron capture detection (ECD) is ideal for identifying molecules with high electron affinities (see class notes).

Molecules which contain halogen atoms are ideally suited for this detection technique.

Thus, $CFCl_3$, CH_3Br and SF_6 would be detected, and CO and CH_4 would not.

15. Explain why the following reaction **does not occur** under ambient conditions (*i.e.*, 25°C, 1 atm):



- (A) I has a smaller atomic radius than Cl
- (B) I has a higher ionization energy than Cl
- (C) I has a higher electronegativity than Cl
- (D) I has a lower electron affinity than Cl
- (E) I has a greater metallic character than Cl

This reaction highlights the halogen activity series. Iodine has a lower electron affinity than Cl, so it is unable to remove electrons from Cl^- . Statement A is simply false. Statement B is false. Statement C is false. Statement E is true, but metallic character describes many possible physical and chemical properties. The most specific answer is Statement D.

16. It was determined experimentally that 15.65 ml of 0.1895 M NaOH was required to reach the equivalence point in a titration with a solution of HCl. Determine the number of grams of HCl contained in the solution.

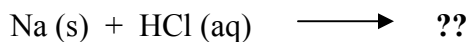
- (A) 0.1081 g
- (B) 0.1000 g
- (C) 0.2489 g
- (D) 0.09873 g
- (E) 0.5689 g

$\text{HCl}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})$
 Mass HCl is required. From the titration data we can determine moles HCl present, then convert to mass.
 The titration is a 1:1 stoichiometry, so moles NaOH = moles HCl.
 $\text{mol NaOH} = c \times V = (0.1895 \text{ mol/L})(0.01565 \text{ L}) = 2.96957 \times 10^{-3} \text{ mol}$
 $\text{mol HCl} = \text{mol NaOH} = 2.96957 \times 10^{-3} \text{ mol}$
 $\text{mass HCl} = \text{mol} \times \text{molar mass} = 2.96957 \times 10^{-3} \text{ mol} \times 36.45 \text{ g/mol}$
 $\text{mass HCl} = 0.1081 \text{ g}$

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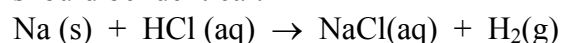
17. Predict all the **products** which are generated in the **reaction** when Na is reacted with an aqueous solution of HCl:



- (A) NaCl (aq), $\frac{1}{2}$ H₂ (g)
- (B) NaOH (aq), $\frac{1}{2}$ H₂ (g), Cl₂ (g)
- (C) NaCl (aq), $\frac{1}{2}$ Cl₂ (g)
- (D) NaOH (aq), $\frac{1}{2}$ H₂ (g)
- (E) Na is not reactive under acidic conditions

In class we have seen the reaction of Na in water, a vigorous redox reaction in which Na is oxidized and protons from water are reduced to H₂(g).

In this case the source of protons is the acid, HCl, but otherwise the redox chemistry should be identical:



18. What is the **average S-O bond order** in the charge-minimized Lewis structure for the sulfate anion (SO₄²⁻)?

- (A) 2
- (B) 1.75
- (C) 1.5
- (D) 1.25
- (E) 1

The charge-minimized Lewis structure for the sulfate anion (SO₄²⁻) has 2 S=O double bonds and 2 S-O single bonds. Thus the average bond order

$$= \frac{\text{total \# of S-O bonds}}{\text{\# of sites for these bonds to occur}}$$
$$= (2+2+1+1) / 4 = 6/4 \text{ or } 1.5$$

19. Which of the following statements is/are **CORRECT**?

- (i) The bonds in CCl_4 are more polar than the bonds in CBr_4 .
- (ii) The formal charge on N in NO_2^- is -1.
- (iii) The molecule BrF_5 has a permanent dipole.

- (A) ii
- (B) iii
- (C) i, ii
- (D) i, iii
- (E) ii, iii

(i) TRUE: A C-Cl bond is more polar than a C-Br bond because Cl is more electronegative than Br.
(ii) FALSE: In the Lewis structure for nitrite we have a single N-O bond, a double N=O bond, and a lone pair of electrons on the N atom. The formal charge on N is therefore: $5 - 2 - 3 = 0$.
(iii) TRUE: BrF_5 is an AX_5E molecule, and so it is a square pyramidal shape (asymmetric shape), and has a permanent dipole.

20. Carbon monoxide is a colourless, toxic gas which binds competitively with oxygen to hemoglobin. How many **nonbonding electrons** are there in the Lewis structure for carbon monoxide?

- (A) 2
- (B) 3
- (C) 4
- (D) 5
- (E) 6

In the Lewis structure for CO there is a carbon-oxygen triple bond, with one lone electron pair each on C and O (thus a total of 2 lone pairs, or 4 lone electrons). As a result, both atoms have an octet of electrons, and there is a -1 formal charge on C and a +1 formal charge on O.

Questions 17-21 are worth three (3) marks each.

21. An aqueous solution of sodium fluoride (187 mL, 0.0620 M) is mixed with an aqueous solution of calcium nitrate (82.1 mL, 0.0923 M). A reaction occurs, producing solid calcium fluoride and aqueous sodium nitrate. **Which starting material is in excess, and by how much (mol)?**

| | <u>Reagent in excess</u> | <u>Amount in excess (mol)</u> |
|-----|-----------------------------------|-------------------------------|
| (A) | Ca(NO ₃) ₂ | 0.00178 |
| (B) | NaF | 0.00363 |
| (C) | NaF | 0.00125 |
| (D) | Ca(NO ₃) ₂ | 0.00216 |
| (E) | NaF | 0.00402 |

The reaction taking place is: $2 \text{NaF(s)} + \text{Ca(NO}_3)_2\text{(aq)} \rightarrow 2 \text{NaNO}_3\text{(aq)} + \text{CaF}_2\text{(s)}$
The ratio of interest is 2 NaF:1 Ca(NO₃)₂.

To determine limiting reagent, determine # moles of each reagent, and see which one does not fulfill the required 2:1 ratio.

$\text{mol NaF} = c \times V = (0.0620 \text{ mol/L})(0.187 \text{ L}) = 0.011594 \text{ mol}$. This would react with $(0.011594 \text{ mol} / 2) = 0.005797 \text{ mol Ca(NO}_3)_2$. Let's see how much Ca(NO₃)₂ we have:
 $\text{mol Ca(NO}_3)_2 = c \times V = (0.0923 \text{ mol/L})(0.0821 \text{ L}) = 0.0075778 \text{ mol}$. Since we have more than enough Ca(NO₃)₂ to react with the NaF, then NaF is the limiting reagent, and Ca(NO₃)₂ is in excess.

$\text{mol in excess} = \text{actual mol} - \text{mol required for reaction} = 0.0075778 - 0.005797 \text{ mol}$
 $\text{mol in excess} = 0.00178 \text{ mol}$

22. Choose the **CORRECT** statements:

- (i) The electron pair geometry in SF₂ is tetrahedral.
- (ii) A molecule with polar bonds must have a permanent dipole.
- (iii) A dipole moment is the product of partial charge and the distance between two atoms.
- (iv) Electronegativity (EN) is the ability of a gas phase atom to attract an electron.
- (v) A bond between two atoms with very small ΔEN is covalent or weakly polar covalent.

- (A) i, iv
- (B) i, iii, v
- (C) ii, iii, iv
- (D) ii, iv, v
- (E) iii, v

(i) TRUE: SF₂ is an AX₂E₂ molecule. It has 4 electron pairs, thus its electron pair geometry is tetrahedral. In its molecular shape we see only the atoms.

(ii) FALSE: In a symmetrical molecule (e.g. CO₂, AX₂), the bond dipoles will cancel out.

(iii) TRUE – definition of dipole moment (see text or class notes).

(iv) FALSE: the definition given is that for electron affinity. Electronegativity describes the ability of an element to compete for electron density in a bond.

(v) TRUE: Intermediate ΔEN leads to polar covalent bonding, and large ΔEN leads to ionic bonding.

23. Select the **TRUE** statements regarding shapes by applying the VSEPR model.

- (i) The VSEPR class of XeF_6 is AX_6 .
- (ii) The F-Xe-F bond angles in XeF_6 are not 90° .
- (iii) The shape of BrF_5 is square pyramidal.
- (iv) The F-Br-F bond angles in BrF_5 are 90° .
- (v) The H-N-H bond angles in NH_3 are smaller than the H-C-H bond angles in CH_4 .

- (A) i, iv
- (B) i, iii, iv
- (C) ii, iii, v
- (D) ii, iv, v
- (E) iii, v

(i) FALSE: XeF_6 has $8+6(7) = 50$ electrons. It has 6 single Xe-F bonds, each F has 3 lone electron pairs and the Xe therefore has a lone electron pair also. Its VSEPR class would be AX_6E .

(ii) TRUE: The shape will not be octahedral because of the lone electron pair on Xe, thus bond angles will not be 90° .

(iii) TRUE: BrF_5 is an AX_5E molecule, with a square pyramidal shape.

(iv) FALSE: In the AX_5E class, the bond angles are non-ideal because of the lone electron pair on the central atom.

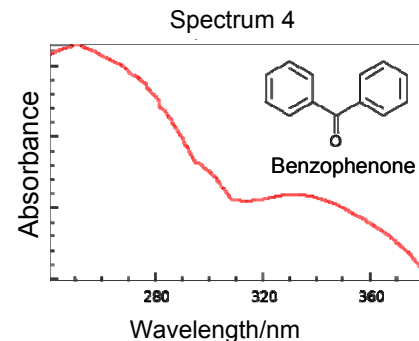
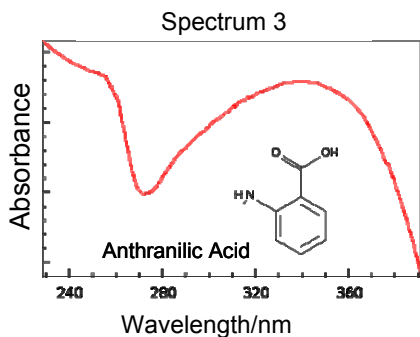
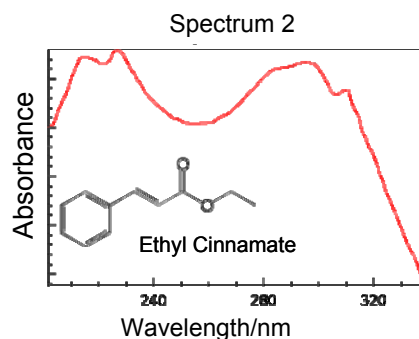
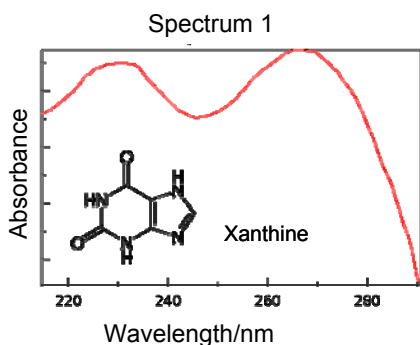
(v) TRUE: CH_4 is an AX_4 molecule, with ideal H-C-H bond angles of 109.5° . The angles in NH_3 are smaller (107°) because it is an AX_3E molecule. The lone electron pair compresses the H-N-H angles.

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25. You are a chemist, working for L'Oreal, producers of Ombrelle, one of Canada's leading sunscreens. You are in search of a new sunscreen ingredient that provides broad-spectrum protection against both UVA (380-320nm) & UVB (320-280nm) radiation.

Based on the following UV spectra, **which one of the following compounds would be the best choice** in the development of this new sunscreen? Note that the 4 figures have **differing scales along the X-axes**, and the Y-axes are equally scaled. Assume absorbance goes to zero beyond the limits shown in each spectrum.



- | | | |
|-----|------------------------------------|------------|
| (A) | Benzophenone | Spectrum 4 |
| (B) | Anthranilic Acid | Spectrum 3 |
| (C) | Ethyl cinnamate | Spectrum 2 |
| (D) | Xanthine | Spectrum 1 |
| (E) | None of the compounds are suitable | |

The best choice of sunscreen ingredient will have the best possible coverage (highest absorbance) in the range 280-380 nm. Of the 4 choices, Spectrum 1 shows absorbance going to 0 at 290 nm (mostly ineffective in the required range). Spectrum 2 goes to zero absorbance at 340 nm – only covers about half the required range. Spectrum 3 shows some degree of coverage over the entire range, with fairly high absorbance over most of the range. Spectrum 4 would be the second choice, as it again has coverage over the entire range, but overall its absorbance values are much lower, particularly as it goes to 0 absorbance at 380.