Name ______________________________ CHM 1045-21
Spring 2020

EXAMINATION THREE – SOLUTIONS

(3 points) You will use the following information for parts of the rest of the exam.

Did you read the "Guidelines and Goals for Exam 3" posted on our course website? If not, please stop and read them now…… Okay, did you read the Guidelines for Exam 3 posted on our course website? __________

Write the number corresponding to your birth month: January = 1, February = 2, etc. __________
(For example, if your birthday is October 16, the number for your birth month would be 10.)

Write the number corresponding to your birth date on that month (1 – 31). __________
(For example, if your birthday is October 16, the number for your birth date would be 16.)

Part 1. (30 points)

After reanalyzed data from NASA's Kepler space telescope, an international team of scientists reported this week the discovery of a planet "most similar to Earth" out of all the planets detected by the Kepler telescope (*The Astrophysical Journal*, **2020**, 893, L27). Located 300 light-years from Earth, this planet, named Kepler-1649c, is like Earth in size and estimated temperature; however, it orbits a red dwarf star very different than our sun. Red dwarf stars are cold (compared to the sun), so the light they emit peaks in the infrared region of the electromagnetic spectrum.

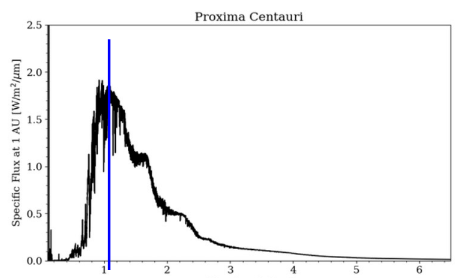
A. (2 pts) In terms of wavelength (in nm) what is the range corresponding to the infrared ~~red~~ region?

from __________ nm to __________ nm

Site your source for the above answer.

Typical range is 750 nm to around 10^6 nm. 2 pts for range starting at 700 nm or higher; -1 pt if no source given.

B. (3 pts) The closest star to us is… okay… the sun. But the second-closest star to us is Proxima Centauri, a red dwarf. The spectrum of light emitted by Proxima Centauri is shown on the right. Its peak emission occurs at the wavelength 1.1 μm (*Astrobiology*, 2018, 18, 133).



Convert 1.1 μm to nm. Be sure to show your work on this and any other calculations.

$1.1\ \mu m \times (10^9\ nm/10^6\ \mu m) = 1.1. \times 10^3\ nm$

(2 pts) So, based on your answer to Part A, does the light emitted by Proxima Centauri peak in the infrared region? __________

Mark this question assuming answer above is correct. IR range is around 700 nm to 10^6 nm.

C. (4 pts) Determine the frequency

From previous page

$1.1\ \mu m \times (10^9\ nm/10^6\ \mu m) = 1.1 \times 10^3\ nm$ (could also start from 1.1 μm)

$$c = \lambda\nu \Rightarrow \nu = c/\lambda = \frac{(2.998 \times 10^8\ m/s)}{1.1 \times 10^3\ nm\ (1\ m/10^9\ nm)} = 2.7_3 \times 10^{14}\ s^{-1}$$

(3 pts) and energy of a photon corresponding to a wavelength of 1.1 μm. Again, show your work and be sure to include the correct units.

$E = h\nu = (6.626 \times 10^{-34}\ J\text{-}s) \times (2.7_3 \times 10^{14}\ s^{-1}) = 1.8_1 \times 10^{-19}\ J$

D. (2 pts) "Kepler-1649c is especially intriguing for scientists looking for worlds with potentially habitable conditions" (www.sciencedaily.com/releases/2020/04/200416105650.htm). If animal life evolved on Kepler-1649c, one might expect its "visible" region to overlap more of the infrared spectrum compared to animals on Earth.

Would Kepler-1649c-lings see red firetrucks better or worse than Earthlings? _______________

Explain your reasoning.

Assign points based on the reason and the answer, not just the answer. In other words, no points if the answer does not match a credible explanation.

Possible answers:

Better, because extending the "visible" region into the infrared would help Kepler-1649c-lings to see red firetrucks. (2 out of 2 pts)

Worse, because if the region is too far into the infrared and not far enough into the Earthling version of visible, then Kepler-1649c-lings would not be able to see the color red. (1 out of 2 pts)

(1 pt) It's also possible that infrared light might not work as well as ROY-G-BIV light for vision. Speculate on why that might be the case.

One possible answer: Maybe the mechanism for detecting photons requires photons higher in energy than the IR. (Not required, but perhaps of interest: Visible light triggers a change in the geometry of a double bond, and that change starts a cascade of events that sends a signal to the brain. IR photons do not have enough energy to trigger that event.)

E. When astrobiologists talk about "potentially habitable conditions," they are usually talking about the so-called "Goldilocks zone," the planetary distance from the star that gives a temperature where H_2O is a liquid (*not too hot, not too cold… just right*). Life on Earth requires water, but sometimes all that water gets in the way. Water absorbs much of the electromagnetic radiation we might use to probe biological processes. Physicists at ETH Zurich recently developed a laser based on x-ray radiation with wavelengths between 2.5 and 4.5 nm (*Optica*, **2020**, *7*, 168). This "soft" x-ray laser can penetrate water because the photons are not absorbed by oxygen; hence, they are not absorbed by water. But they are absorbed by carbon, "ideal for studying organic molecules and biological specimens in their natural aqueous environment."

(8 pts) The atoms are detected by exciting the core electrons in the 1s orbital. The energy required for carbon is 4.62×10^{-17} J. Calculate the wavelength (in nm) corresponding to a 4.62×10^{-17} J photon.

$$E = h\nu \;\Rightarrow\; \nu = E/h = \frac{(4.62 \times 10^{-17}\ \text{J})}{6.626 \times 10^{-34}\ \text{J·s}} = 6.97_3 \times 10^{16}\ \text{s}^{-1}$$

$$c = \lambda\nu \;\Rightarrow\; \lambda = c/\nu = (2.998 \times 10^{8}\ \text{m/s}) / (6.97_3 \times 10^{16}\ \text{s}^{-1}) = 4.30 \times 10^{-9}\ \text{m}$$

$$4.30 \times 10^{-9}\ \text{m} \times (10^{9}\ \text{nm/m}) = 4.30\ \text{nm}$$

(2 pts) So, are the 4.62×10^{-17} J photons needed to detect carbon atoms in the 2.5 to 4.5 nm range produced by the ETH laser? ___________

Mark this question assuming answer above is correct.

(2 pts) The energy required to excite the 1s electrons in oxygen is 8.62×10^{-17} J. Will the 2.5 to 4.5 nm photons produced by the ETH laser detect oxygen atoms? ___________

Explain your reasoning.

Even without doing the calculation, probably not. The energy for oxygen is almost double, so the frequency will be almost double, and the wavelength will be a little less than half – around 2.3 to 2.4 nm, outside the range.

To be safe, we could go through the calculation again and get 2.41 nm, just under the 2.5 to 4.5 nm range, but the above argument is sufficient to see why oxygen would not be detected (or not detected well) by 2.5 -4.5 nm photons.

Part 2. (20 points)

One of the reasons we studied electromagnetic radiation (aka light) this semester was to better understand the behavior of waves so we could recognize that behavior in particles of matter.

A. (6 pts) As the mass of a particle increases, does the wavelength of that particle increase, remain the same, or decrease? decrease

Explain your reasoning.

$\lambda = h/mv$ So as mass in the denominator increases, the wavelength decreases.

So, as the mass of a particle increases, will it be easier or harder to observe the wave-like behavior of that particle? harder

B. (10 pts) Scientists at University of Vienna recently reported on their work to push the limits of detecting evidence for matter waves (*Nature Physics*, **2019**, *15*, 1242). Working with chemists at the University of Basel who prepared who synthesized the compounds (derivatives of porphyrin), they investigated molecules with masses greater than 25,000 amu. For example, one of the largest molecules used in their study, $C_{707}H_{260}F_{908}N_{16}S_{53}Zn_4$, corresponds to a mass of 28,189 amu. Under their experimental conditions, the velocity of the molecule was determined to be 261 m/s.

Calculated the wavelength of the molecule based on the information provided above, using the approach we discussed in class (not the more advanced theory in the *Nature Physics* paper). Any constants or conversion factors you might need can be found in our text, the old info handout on our website, or elsewhere on the Interweb. Show your work, include units, blah, blah, blah.

28,189 amu $(1.66 \times 10^{-24}$ g/amu$) \times (1$ kg/1000 g$) = 4.67_9 \times 10^{-23}$ kg

$\lambda = h/mv = 6.626 \times 10^{-34}$ J·s/[$(4.67_9 \times 10^{-23}$ kg$) \times (261$ m/s$)$] $= 5.42 \times 10^{-14}$ m

C. (2 points) What else do you need to know to determine if wave mechanics is needed to describe the behavior of $C_{707}H_{260}F_{908}N_{16}S_{53}Zn_4$?

Need to know the size of the molecule to see how that compares to the wavelength.

D. (2 points) *ScienceDaily* reported on this work in an article titled ***2000 atoms in two places at once*** (www.sciencedaily.com/releases/2019/10/191002075929.htm). Catchy title, but what are they talking about? (Short answer; do not exceed the space provided from here to the blue line.

More than one acceptable answer:

At the quantum level, cannot know where the bit of matter is; can only know the probability of is being in a region of space.

The bit of matter can be in this place, or that place, or both places, or neither place.

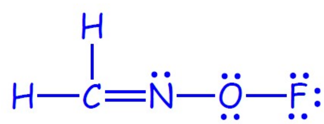
Part 3. (35 points)

A. Preparing for the dystopian society likely to emerge after COVID-19, my family has focused on building up our stockpile of OxiClean™ and Flex Seal™. The active ingredient in OxiClean is sodium percarbonate, and the chemical formula is often written as $Na_2H_3CO_6$, but it is really a solid composed of Na_2CO_3 and H_2O_2 in a 2:3 ratio. If the chemical formula was $Na_2H_3CO_6$, that would mean there is an ion with the formula $H_3CO_6^{2-}$ stable enough to be stored in a bag at room temperature for months or even years. You get ready to try to write a reasonable dot structure for this ion, but before you even start speculating on how the atoms are connected, you decide that it is unlikely to be stable.

(2 pts) Explain how you reached that conclusion.

An ion with the formula $H_3CO_6^{2-}$ would have an odd number of electrons, so it would likely be unstable.

B. I mentioned in class that the molecules you most care about contain carbon, nitrogen, oxygen, and fluorine. I should have included hydrogen. Let's try to build a molecule using those elements in the order they appear on the periodic table. Write the best dot structure you can for the molecule H_2CNOF, where the atoms are connected as written (except both hydrogen atoms are bonded to carbon). Be sure to include all nonzero formal charges.

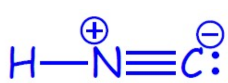


(2 pts) It would have been cooler to use every atom once, HCNOF, except that molecule probably would not be very stable. Why not?

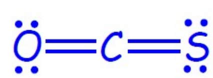
HCNOF would have an odd number of electrons, so it would probably be unstable.

C. Write the best dot structure you can for the following molecules. Be sure to include all nonzero formal charges.

1. HNC 1+5+4 = 10 valence e^-

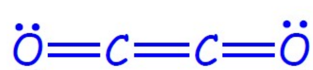


2. OCS 6+4+6 = 16 valence e^-



3. NSCl 5+6+7 = 18 valence e^-

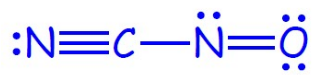
4. OCCO 6+4+4+6 = 20 valence e^-



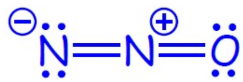
C. (continued) Write the best dot structure you can for the following molecules. Be sure to include all nonzero formal charges.

5. NNO 5+5+6 = 16 valence e⁻

6. NCNO 5+4+5+6 = 20 valence e⁻



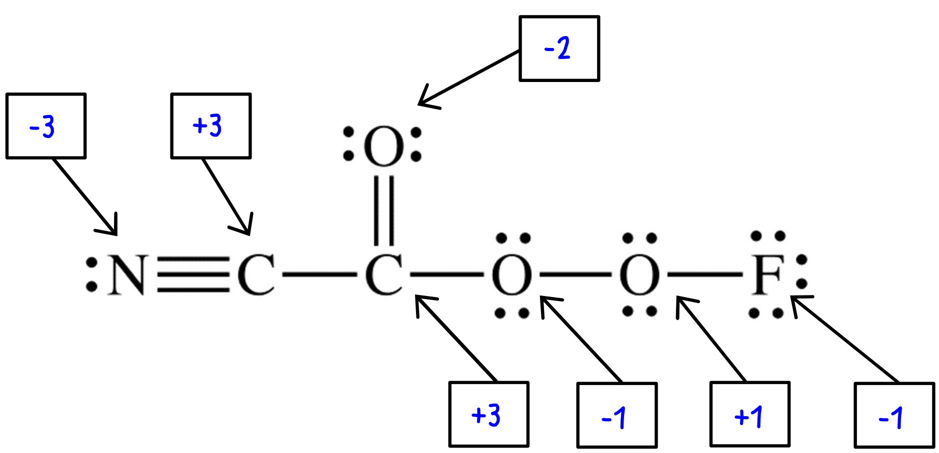
D. Draw a resonance structure for the dot structure you drew for NNO in Part C.5 (above left), and as always, assign all nonzero formal charges.



You wrote the best dot structure you could for NNO in Part C. So why is the dot structure of NNO you wrote for Part D not as good as the one you wrote for Part C?

The dot structure in Part D gives a negative formal charge to the terminal nitrogen. It is better to place the negative formal charge on the more electronegative oxygen atom.

E. While reading about sodium percarbonate for the OxiClean question in Part A, I ran across its use in the preparation of specialized oxidizing agents. A hypothetical example is shown below. Write the oxidation number for each atom in the box provided.



Part 4. (15 points)

A. Write down your birth date from the top of Part 1. It will be a number from 1 to 31. _______

Write the electron configuration for an atom that has the same atomic number as your birth date. For example, if your birth date is 35, you would write the electron configuration for a bromine atom. If you prefer, you may use the appropriate noble gas symbol in brackets to represent the inner-core electrons.

Depends on birth date. For example, if birth date is 12, that corresponds to magnesium, giving

$1s^2 2s^2 2p^6 3s^2$, or simply $[Ne]3s^2$

Subtract your birth date from 35 and write that number here. __________

Write the electron configuration for an atom that has the same atomic number as 35 minus your birth date.

35 - 12 = 23, corresponding to vanadium

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^3$, or simply $[Ar]4s^2 3d^3$

(1 point) Is it possible that the two electron configurations you wrote above will be the same? Explain your reasoning.

No. Lots of ways to explain way; here's one: The midpoint of an odd number is not a whole number, so you cannot subtract a whole number from 35 and get the same number you subtracted from 35.

B. A silicone atom is larger than a sulfur atom. Why?

Sulfur has a greater effective nuclear charge, so it pulls the outer electrons in closer.

C. Write the values of n, ℓ, and m_ℓ for the highest energy electron in a cesium atom.

n = 6 ℓ = 0 m_ℓ = 0

D. Remember way back in ***Part 1.D*** when we noted that the energy required to excite electrons in the 1s orbital for carbon (4.62×10^{-17} J) was less than the energy required to excite electrons in the 1s orbital for oxygen (8.62×10^{-17} J)?

Why does it take less energy to excite electrons in the 1s orbital for carbon?

The charge of the carbon nucleus is less than the charge of the oxygen nucleus (6+ and 8+, respectively). The carbon nucleus has the lower charge, so it takes less energy to pull the 1s electrons away from the nucleus.