Exam II Makeup Questions

H. Ryott Glayzer

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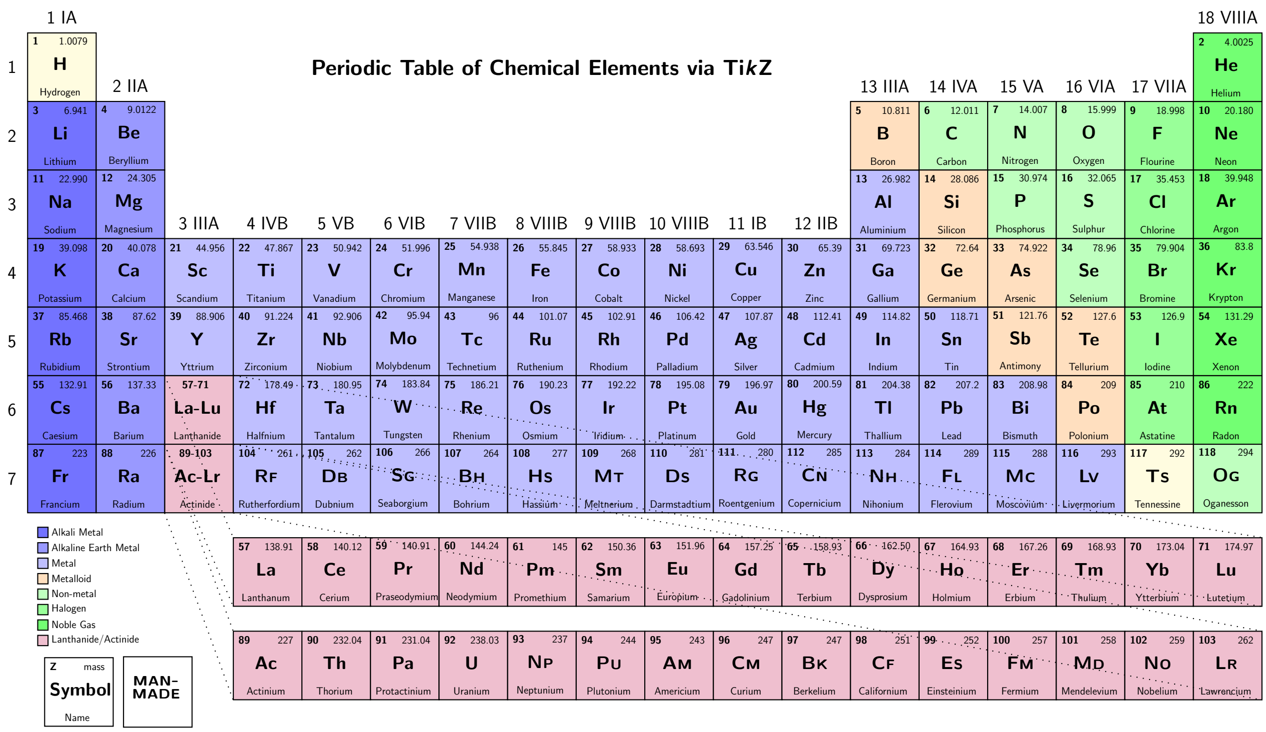
Notice of ADA Accommodation and Methods

I have an ADA accommodation to do my assignment on paper. This document is a utilization of that accommodation. This assignment will utilize the makeup questions for Exam II provided by Dr. Moulder. Reasoning will be provided within the context of this class, and at times, within the context of concepts outside of the scope of this class. Each problem will appear on a new page.



Calculate the Velocity of Electrons with de Broglie Wavelengths of 285 nm.

The equation

$$\lambda = \frac{h}{mv}$$

is accurate for non-relativistic velocities. For relativistic velocities, the equation

$$\frac{1}{\lambda_B} = \frac{mv}{h\sqrt{1 - \frac{v^2}{c^2}}}$$

is more accurate. I will determine the velocity of electrons with de Broglie wavelengths of 285 nm using both of these equations.

Calculating the de Broglie Wavelength with the Non-Relativistic Equation

For the non-relativistic equation, we will first consider that the mass of an electron is given to be 9.1094 x 10^{-31} kg. The non-relativistic equation:

$$\lambda = \frac{h}{mv}$$

can be rewritten:

$$h = mv\lambda.$$

To determine the velocity, we can rearrange the equation to give the velocity:

$$v = \frac{h}{m\lambda}.$$

Substituting the variables with known values, with the knowledge that $1\,\mathrm{J} = 1\,\mathrm{kg\,m^2\,s^{-2}}$, gives:

$$v = \frac{6.63 \times 10^{-34}\,\mathrm{kg\,m^2\,s^{-2}\,s}}{9.1094 \times 10^{-31}\,\mathrm{kg} \times 2.85 \times 10^{-7}\,\mathrm{m}}.$$

This gives:

$$v\,\mathrm{m\,s^{-1}} = \frac{6.63 \times 10^{-34}\,\mathrm{kg\,m^2\,s^{-1}}}{2.596\,179 \times 10^{-37}\,\mathrm{kg\,m}}$$

which provides the value:

$$v = 2.553\,753\,035 \times 10^3\,\mathrm{m\,s^{-1}} = 2.553 \times 10^3\,\mathrm{m\,s^{-1}}$$

This value is closest to multiple choice option **D:** $2.552 \times 10^3\,\mathrm{m\,s^{-1}}$.

Calculating the de Broglie wavelength using the Proper Relativistic Equation

The de Broglie wavelength of a particle is a wavelength that determines the probability density of the particle being found at a specific point q in its configuration space. This is important in quantum mechanics. In the context of General Chemistry I, the de Broglie wavelength is defined in our textbook only as a characteristic of particles and other bodies. The relativistic definition of the de Broglie wavelength is:

$$\lambda_B = \frac{h}{p},$$

where λ_B represents the de Broglie wavelength of the particle, h represents the Planck constant, which has the value $6.626\,070\,15 \times 10^{-34}$ J s, and p represents the relativistic momentum of the particle, defined as

$$p = \frac{mv}{\sqrt{1 - \frac{v^2}{c^2}}},$$

with m representing the mass of the particle, v representing the particle's velocity, and c representing the speed of light in a vacuum. The invariant mass of the electron is approximately $9.109\,383\,701\,5(28) \times 10^{-31}$ kg according to the NIST. The speed of light in a vacuum is defined as $299\,792\,458\ \mathrm{m\,s^{-1}}$.

Combining these equations gives the formula:

$$\lambda_B = \frac{h}{\frac{mv}{\sqrt{1-\frac{v^2}{c^2}}}}$$

which simplifies to

$$\lambda_B = \frac{h\sqrt{1 - \frac{v^2}{c^2}}}{mv}.$$

This can be rearranged to

$$\lambda_B mv = h\sqrt{1 - \frac{v^2}{c^2}}.$$

root -? The following steps will solve the equation for velocity:

$$\frac{\lambda_B mv}{h} = \sqrt{1 - \frac{v^2}{c^2}} \Rightarrow (\frac{\lambda_B mv}{h})^2 = (\sqrt{1 - \frac{v^2}{c^2}})^2 \Rightarrow \frac{\lambda_B^2 m^2 v^2}{h^2} = 1 - \frac{v^2}{c^2} \Rightarrow$$

$$1 = \frac{\lambda_B^2 m^2 v^2}{h^2} + \frac{v^2}{c^2} \Rightarrow 1 = \frac{\lambda_B^2 m^2 v^2 c^2 + v^2 h^2}{h^2 c^2} \Rightarrow h^2 c^2 = \lambda_B^2 m^2 v^2 c^2 + v^2 h^2 \Rightarrow$$

$$h^2 c^2 = v^2(\lambda_B^2 m^2 c^2 + h^2) \Rightarrow v^2 = \frac{h^2 c^2}{\lambda_B^2 m^2 c^2} \Rightarrow v = \sqrt{\frac{h^2 c^2}{\lambda_B^2 m^2 c^2}}$$

$$v = \sqrt{\frac{h^2}{\lambda_B^2 m^2}}$$

And thus, we have arrived at the relativistic equation for the de Broglie wavelength solved for velocity. Using the values we defined earlier, we find the velocity to be:

$$v^2 = \frac{(6.626\,070\,15 \times 10^{-34}\,\mathrm{J\,s})^2}{(285 \times 10^{-9}\,\mathrm{m})^2 \times (9.109\,383\,701\,5 \times 10^{-31}\,\mathrm{kg})^2}$$

$$v^2 = \frac{4.390\,480\,563 \times 10^{-67}\,\mathrm{kg^2 m^4 s^{-2}}}{6.740\,121\,281 \times 10^{-74}\,\mathrm{kg^2\,m^2}}$$

$$v^2 = 6.513\,948\,904 \times 10^{6}\,\mathrm{m^2\,s^{-2}}$$

$$v = 2.552\,243\,896 \times 10^{3}\,\mathrm{m\,s^{-1}},$$

which, upon applying significant figures, would come to

$$v = 2.552 \times 10^{3}\,\mathrm{m\,s^{-1}}$$

This is exactly the multiple choice option **D**.

Solution

Both the non-relativistic approximation and the true relativistic equation give the answer

$$\mathbf{D}.\quad 2.552 \times 10^{3}\,\mathrm{m\,s^{-1}}.$$

What Element is Theoretically the Smallest of all on the Periodic Table?

The smallest theoretical element is Helium. This follows the periodic trends of atomic radius. As an element's group grows, its radius shrinks as there are more electrons in its shell, and the radius grows as the period increases, as there are more electron shells. Since Hydrogen has the most electrons and the least electron shells, Helium is the smallest element.

What wavelength would the hydrogen Rydberg line give for the electronic transition $n_1 = 2$ and $n_2 = 5$?

The Rydberg formula models the emission and absorption wavelengths for photons in jumps in electron energy levels. It is defined for hydrogen as follows:

$$\frac{1}{\lambda_{vac}} = R_H \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

where R_H is defined in the handout as $1.097 \times 10^7\,\mathrm{m}^{-1}$. This gives us the equation

$$\frac{1}{\lambda_{vac}} = \left(1.097 \times 10^7\,\mathrm{m}^{-1}\right) \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

The problem is asking for the Rydberg line for $n_1 = 2$ and $n_2 = 5$. Plugging these into the formula gives us

$$\frac{1}{\lambda_{vac}} = \left(1.097 \times 10^7\,\mathrm{m}^{-1}\right) \left(\frac{1}{4} - \frac{1}{25} \right)$$

Fraction Subtraction rules tell us that we need to find a common denominator.

$$\frac{1}{\lambda_{vac}} = R_H \left(\frac{25}{100} - \frac{4}{100} \right) = R_H \left(\frac{21}{100} \right)$$

From this, we can see that

$$\lambda_{vac} = \frac{100}{21 \times 1.097 \times 10^7\,\mathrm{m}^{-1}}$$

Which gives us

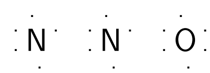
$$\lambda_{vac} = 4.341 \times 10^{-7}\,\mathrm{m}$$

which is approximately equal to 434.0 nm.

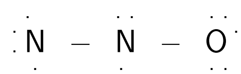
Thus, the wavelength of the hydrogen Rydberg line for the electronic transition from 2 to 5 would be 434.0 nm, or multiple choice option **C**.

Which is the most correct Lewis structure for N_2O

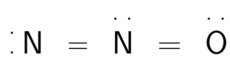
Both Nitrogen and Oxygen in N_2O can be the central atom, so we determine the central atom by determining the least electronegative atom and placing it in the middle. N has electronegativity 3.04, while O has electronegativity 3.44. Thus, Nitrogen will be the central atom.
There are five valence electrons in each nitrogen atom, and six in the oxygen atom. Thus, there are sixteen total valence electrons in N_2O.
Next, we must draw the skeleton structure for N_2O.



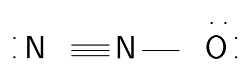
Now, we connect each atom with the central atom with a single bond.



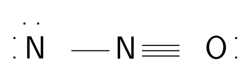
Now, we must create new bonds in the central atom to create double and triple bonds.



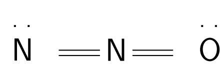
The N atom on the end does not follow the octet rule. Thus, we must move around bonds to make it valid.



This works, but there are resonance structures:



and



Now, we must compute the formal charges of each of the above resonance structures. Formal Charge can be calculated via the following

$$\mathbf{Q}_{\text{Formal}} = \mathbf{V}_{e^-} - \mathbf{LP}_{e^-} - \frac{\mathbf{B}_{e^-}}{2}$$

For the first structure, $N \equiv N - O$, the Formal Charge is computed:

$$\mathbf{N}_{edge} : 5 - 2 - \frac{6}{2} = 0$$

$$\mathbf{N}_{central} : 5 - 0 - \frac{8}{2} = +1$$

$$\mathbf{O} : 6 - 6 - \frac{2}{2} = -1$$

Thus the formal charge of the first resonance structure, $N \equiv N - O$, is $0 + 1 - 1 = 0$. This has the negative charge on the Oxygen and the positive charge on the Nitrogen. The Oxygen is the more electronegative of the two, so this is the most correct structure for N_2O:

$$:N \equiv N - \underset{\cdot\cdot}{\overset{\cdot\cdot}{O}}:$$

This version is close to multiple choice option **D**.

What is the Frequency of Light that has a wavelength of 185 nm?

The frequency of a photon can be derived in a classical sense through

$$\lambda = \frac{\mathrm{c}}{\nu}$$

as such

$$\nu = \frac{c}{\lambda}$$

We can input the necessary values for c and λ.

$$\nu = \frac{3.00 \times 10^{8}\,\mathrm{m\,s^{-1}}}{185 \times 10^{-9}\,\mathrm{m}}$$

this gives us the value

$$\nu = 1.62 \times 10^{15}\,\mathrm{s^{-1}}$$

This is the value of the multiple choice option **E**.

Which element is most likely to present with the first five ionization energies specified below? (in $\mathrm{kJ\,mol^{-1}}$)

589.8	1145	4912	6491	8153

These five ionization energies are increasing in order. Since the third ionization energy is exhibits a great increase, and it is greatly difficult to remove an electron from a full octet, one can assume that the atom has two valence electrons. Looking at the provided options, the only group 2 element in Calcium. Thus, one can assume the answer is Calcium, multiple choice option **B**.

What is the hybridization of all the carbon atoms in benzene (C_6H_6)?

Based on their electronic configurations, which of the following elements or ions is paramagnetic in a vapor phase?

What is the maximum number of electrons that can have the following set of quantum numbers: n = 4, l = 3 m_l = 3, m_s = $-\frac{1}{2}$

Order the following series of isoelectronic ions (Mg^{2+}, N^{3-}, F^{-}, Si^{4+}) from largest to smallest ionic radii.