## Chem 131

Exam 1, Ch 8-10
100 Points
Please follow the instructions for each section of the exam. Show your work on all mathematical problems. Provide answers with the correct units and significant figures. Be concise in your answers to discussion questions.

## Part 0: Warmup. 4 points each

1. Which of the following electronic transitions in a hydrogen atom results in the emission of light of the highest frequency?
a. $n=4$ to $n=3$
b. $\mathrm{n}=2$ to $\mathrm{n}=1$
c. $n=6$ to $n=1$
d. $\mathrm{n}=3$ to $\mathrm{n}=2$
2. Which of the following has the largest diameter?
a. argon atom
b. potassium ion
c. calcium ion
d. chloride ion

## Part I: Complete all of problems 3-6

3. Define the following using a maximum of two sentences for each definition. (12 points)
a. resonance: Resonance is invoked when two or more reasonable Lewis Structures can be drawn for a single species. The real structure is a hybrid on the different contributing structures.
b. radial node: Region in space a constant distance from the nucleus where there $\psi^{2}$ (probability of finding an electron) is zero.
c. wavefunction: Mathematical expression that describes a solution to the Schrodinger equiation and reflects an orbital for an electron in an atom (typically hydrogen).
4. Write the ground state electron configurations for the following species. You may choose to use noble gas notation if you wish. (12 points)

| a. Iodine | $[\mathrm{Kr}] 5 \mathrm{~s}^{2} 4 \mathrm{~d}^{10} 5 \mathrm{p}^{5}$ |
| :--- | :--- |
| b. sulfide ion | $[\mathrm{Ar}]$ |
| c. chromium | $[\mathrm{Ar}] 4 \mathrm{~s}^{1} 3 \mathrm{~d}^{5}$ |
| d. iron (II) ion | $[\mathrm{Ar}] 3 \mathrm{~d}^{6}$ |

5. Complete the table for two (2) of the species below: (12 points)

| Species | Lewis Structure (indicate resonance if necessary) | Electron Pair Geometry | Molecular Geometry | Polar Molecule? (yes/no) |
| :---: | :---: | :---: | :---: | :---: |
| $\mathrm{NH}_{3}$ | $\mathrm{H}-\ddot{\mathrm{N}} \underset{\mathrm{I}}{\mathrm{H}}$ | tetrahedral | trigonal pyramidal | yes |
| $\mathrm{ClF}_{3}$ |  | trigonal bipyramidal | T-shaped | yes |
| $\mathrm{SO}_{2}$ | $\ddot{O}-\ddot{S}=\ddot{\mathrm{O}}$. $\longleftrightarrow \ddot{\mathrm{O}}=\ddot{\mathrm{S}}-\ddot{\mathrm{O}}$ : | trigonal planar | bent | yes |

6. Below are the Lewis structures for two compounds. For each compound, name the molecular geometry and provide a three dimensional sketch of the compound. Indicate approximate bond angles (12 points)
a. $\mathrm{H}_{2} \mathrm{~S}$


Bent molecular geometry

$<109.5^{\circ}$
b. $\mathrm{IF}_{5}$


Square pyramidal geometry

## Part II. Answer three (3) of problems 7-10. Clearly mark the problem you do not want graded. 15 points each.

7. Consider the general trends in second ionization energy, as shown in the figure to the right. The second ionization energy is for the reaction:

$$
\mathrm{M}^{+}(\mathrm{g}) \rightarrow \mathrm{M}^{2+}(\mathrm{g})+\mathrm{e}^{-}
$$


a. Why are the second ionization energies of the group two atoms (Li-Ne) larger than those of the group three atoms ( $\mathrm{Na}-\mathrm{Ar}$ )?

In general, period two elements have a larger effective nuclear charge than the elements below them in period three. This is due, in part, to the fact that there are fewer electrons available to shield the charge of the nucleus. With this larger $Z^{*}$, it is more difficult to remove an electron (or two electrons as is this case) from the elements in the second row than for those in the third.
b. Why is there a large decrease from Li to Be and then a general increase as you move across the group to Ne ?

Ffor the jump from Be to Li , the second ionization energy requires the formation of $\mathrm{Li}^{2+}$ from $\mathrm{Li}^{+}$Since both $\mathrm{Li}^{+}$has a noble gas configurations, there is a large price to pay in energy.
8. Organic compounds containing nitro groups $\left(-\mathrm{NO}_{2}\right)$ often possess very explosive characteristics. Nitromethane $\left(\mathrm{CH}_{3} \mathrm{NO}_{2}\right)$ is the simplest of these nitrated organic compounds. It undergoes combustion by the following reaction

$$
2 \mathrm{CH}_{3} \mathrm{NO}_{2}(\mathrm{~g})+\mathrm{O}_{2}(\mathrm{~g}) \rightarrow 2 \mathrm{CO}_{2}(\mathrm{~g})+2 \mathrm{H}_{2} \mathrm{O}(\mathrm{~g})+\mathrm{N}_{2}(\mathrm{~g})
$$



The Lewis structure of nitromethane is shown at the right. Using the table of bond dissociation energies on the last page of the exam, determine the $\Delta H^{\circ}$ for this reaction.

In order to rearrange the atoms in the reactants to form products, we need to break and make the following bonds:

Bonds Broken:

| Bond | $\mathrm{N}-\mathrm{O}$ | $\mathrm{N}=\mathrm{O}$ | $\mathrm{C}-\mathrm{N}$ | $\mathrm{C}-\mathrm{H}$ | $\mathrm{O}=\mathrm{O}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Quantity | 2 | 2 | 2 | $2 \times 3=6$ | 1 | Total |
| Energy (kJ) | $2(201)$ | $2(852)$ | $2(305)$ | $6(413)$ | 498 | 5692 |

Bonds Formed:

| Bond | $\mathrm{C}=\mathrm{O}$ | $\mathrm{H}-\mathrm{O}$ | $\mathrm{N} \equiv \mathrm{N}$ |  |
| :---: | :---: | :---: | :---: | :---: |
| Quantity | $2 \times 2=4$ | $2 \times 2=4$ | 1 | Total |
| Energy (kJ) | $4(732)$ | $4(463)$ | 945 | 5725 |

$\Delta H^{\circ}=($ Total for bonds broken $)-($ Total for bonds formed $)=5692-5725=-33 \mathrm{~kJ}$
Now with the correctly balanced reaction!

$$
4 \mathrm{CH}_{3} \mathrm{NO}_{2}(\mathrm{~g})+3 \mathrm{O}_{2}(\mathrm{~g}) \rightarrow 4 \mathrm{CO}_{2}(\mathrm{~g})+6 \mathrm{H}_{2} \mathrm{O}(\mathrm{~g})+2 \mathrm{~N}_{2}(\mathrm{~g})
$$

Bonds Broken:

| Bond | $\mathrm{N}-\mathrm{O}$ | $\mathrm{N}=\mathrm{O}$ | $\mathrm{C}-\mathrm{N}$ | $\mathrm{C}-\mathrm{H}$ | $\mathrm{O}=\mathrm{O}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Quantity | 4 | 4 | 4 | $4 \times 3=12$ | 3 | Total |
| Energy (kJ) | $4(201)$ | $4(852)$ | $4(305)$ | $12(413)$ | $3(498)$ | $\mathbf{1 1 8 8 2}$ |

Bonds Formed:

| Bond | $\mathrm{C}=\mathrm{O}$ | $\mathrm{H}-\mathrm{O}$ | $\mathrm{N} \equiv \mathrm{N}$ |  |
| :---: | :---: | :---: | :---: | :---: |
| Quantity | $4 \times 2=8$ | $6 \times 2=12$ | 2 | Total |
| Energy (kJ) | $8(732)$ | $12(463)$ | $2(945)$ | 13302 |

$\Delta H^{\circ}=($ Total for bonds broken $)-($ Total for bonds formed $)=11882-13302=-1420 \mathrm{~kJ}$
9. The Lewis structure for the thiocyanate ion (a polyatomic anion comprised of one atom each of $\mathrm{C}, \mathrm{N}$, and S ) could be drawn in several ways, three of which are shown below. Which of these structures is more likely to be representative of the real structure of thiocyanate? Explain your reasoning.


I


II


III

To begin, we need to calculate the formal charges on each atom in each structure.

| Structure | Formal Charge on S | Formal Charge on C | Formal Charge on N |
| :---: | :---: | :---: | :---: |
| I | 0 | 0 | -1 |
| II | +2 | -2 | -1 |
| III | 0 | -2 | +1 |

Since a goal in the drawing of Lewis Structures (and in the formation of compounds) is to minimize formal charge on atoms in the compound, structure I appears most favored.
Structures II and III each have atoms with large formal charge, while structure I has only one atom with a nonzero formal charge.
10. Consider the following diagrams of the same orbital. Which orbital do the pictures represent? Provide the values for $\mathrm{n}, \ell$, and m , for the orbital and justify your reasoning.



To assign values for n and $\ell$, we need to look for nodes in the orbitals. From the probability plot on the right, it appears that there are one angular node in this orbital. For this to be true, the value of $\ell$ must be 1 , resulting in a p orbital. From the plots above, we observe only one radial node in the orbital, as evidenced by the one location outside the nucleus where the Distribution Function is zero (above left) and the one circular interface between the grey and black phases in the Probability Density plot (above right). Therefore $\mathrm{n}-\ell-1$ must equal 1. If $\ell=1$, then the value of $n$ must be $\underline{\mathbf{3}}$. With $n=3$, and $\ell=1$, we must have a $3 \mathbf{p}$ orbital. The third quantum number, $m_{c}$ depends on the value of $\ell\left(m_{\iota}\right.$ ranges from $-\ell$ through zero to $+\ell$ ). Since $\ell=1$ for this orbital, there are three possible value of $m_{c}(1-, 0,+1)$. Any of the three values will be acceptible So,

$$
\begin{gathered}
\mathrm{n}=3 \\
\ell=1 \\
\mathrm{~m}_{c}=-1,0,+1
\end{gathered}
$$

Possibly Useful Information

| $h=6.63 \times 10^{-34} \mathrm{Js}$ | $c=3.00 \times 10^{8} \mathrm{~m} / \mathrm{s}$ | $\mathrm{R}_{\mathrm{H}}=2.179 \times 10^{-18} \mathrm{~J} /$ atom |
| :---: | :---: | :---: |
| $\mathrm{E}=\mathrm{h} \nu$ | $v \lambda=\mathrm{c}$ | $\Delta \mathrm{E} \cdot \Delta(\mathrm{mv})>\mathrm{h}$ |
| $\mathrm{H} \psi=\mathrm{E} \psi$ | $\mathrm{E}=-\frac{\mathrm{R}_{\mathrm{H}}}{\mathrm{n}^{2}}$ | $\Delta \mathrm{E}=-\mathrm{R}_{\mathrm{H}}\left(\frac{1}{\mathrm{n}_{\text {final }}^{2}}-\frac{1}{\mathrm{n}_{\text {initial }}^{2}}\right)$ |

## TABLE 10.3 Some Average Bond Energies ${ }^{\text {a }}$

|  | Bond <br> Energy, <br> $\mathrm{kJ} / \mathrm{mol}$ | Bond | Bond <br> Energy <br> $\mathrm{kJ} / \mathrm{mol}$ | Bond | Bond <br> Energy <br> $\mathrm{kJ} / \mathrm{mol}$ |
| :--- | :--- | :--- | :--- | :--- | :--- |
| $\mathrm{H}-\mathrm{H}$ | 436 | $\mathrm{C}-\mathrm{C}$ | 347 | $\mathrm{~N}-\mathrm{N}$ | 163 |
| $\mathrm{H}-\mathrm{C}$ | 414 | $\mathrm{C}=\mathrm{C}$ | 611 | $\mathrm{~N}=\mathrm{N}$ | 418 |
| $\mathrm{H}-\mathrm{N}$ | 389 | $\mathrm{C} \equiv \mathrm{C}$ | 837 | $\mathrm{~N} \equiv \mathrm{~N}$ | 946 |
| $\mathrm{H}-\mathrm{O}$ | 464 | $\mathrm{C}-\mathrm{N}$ | 305 | $\mathrm{~N}-\mathrm{O}$ | 222 |
| $\mathrm{H}-\mathrm{S}$ | 368 | $\mathrm{C}=\mathrm{N}$ | 615 | $\mathrm{~N}=\mathrm{O}$ | 590 |
| $\mathrm{H}-\mathrm{F}$ | 565 | $\mathrm{C} \equiv \mathrm{N}$ | 891 | $\mathrm{O}-\mathrm{O}$ | 142 |
| $\mathrm{H}-\mathrm{C} 1$ | 431 | $\mathrm{C}-\mathrm{O}$ | 360 | $\mathrm{O}=\mathrm{O}$ | 498 |
| $\mathrm{H}-\mathrm{Br}$ | 364 | $\mathrm{C}=\mathrm{O}$ | $736^{\mathrm{b}}$ | $\mathrm{F}-\mathrm{F}$ | 159 |
| $\mathrm{H}-\mathrm{I}$ | 297 | $\mathrm{C}-\mathrm{C} 1$ | 339 | $\mathrm{C} 1-\mathrm{C} 1$ | 243 |
|  |  |  |  | $\mathrm{Br}-\mathrm{Br}$ | 193 |
|  |  |  |  | $\mathrm{I}-\mathrm{I}$ | 151 |


| 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | $\begin{aligned} & 18 \\ & 8 \mathrm{~A} \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1A |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| $\begin{gathered} 1 \\ \hline \text { H } \\ 1.00794 \end{gathered}$ | $\underset{2 \mathrm{~A}}{2}$ |  |  |  |  |  |  |  |  |  |  | $\begin{aligned} & 13 \\ & 3 \mathrm{~A} \end{aligned}$ | $14$ | $15$ | $16$ | $\begin{aligned} & 17 \\ & 7 \mathrm{~A} \end{aligned}$ | $\begin{gathered} 2 \\ \mathrm{He} \end{gathered}$ |
|  | $\begin{gathered} \text { Be } \\ \text { Be } \\ 9.01218 \end{gathered}$ |  |  |  |  |  |  |  |  |  |  | $\begin{array}{\|c} 5 \\ \text { B } \\ 10.811 \\ \hline \end{array}$ | $\underset{12.011}{\stackrel{6}{C}}$ | $\stackrel{\substack{5 A \\ \stackrel{7}{N} \\ 14.0067}}{ }$ | $\begin{gathered} \stackrel{8}{\mathrm{O}} \\ 15999 \end{gathered}$ |  | $\begin{array}{\|c\|} \hline 10 \\ \mathrm{Ne} \\ \text { 20.197 } \end{array}$ |
| $\begin{gathered} \mathrm{Na} \\ \mathrm{Na} \\ 22.998 \end{gathered}$ | $\begin{array}{\|c\|} \hline 12 \\ \mathrm{Mg} \\ \hline \end{array}$ | $\begin{gathered} 3 \\ 3 B \end{gathered}$ | $\begin{gathered} 4 \\ 4 \mathrm{~B} \end{gathered}$ | $\begin{gathered} 5 \\ 5 B \end{gathered}$ | $\begin{gathered} 6 \\ 6 B \end{gathered}$ | $\begin{gathered} 7 \\ 7 \mathrm{~B} \end{gathered}$ |  | $\begin{gathered} 9 \\ -8 B \end{gathered}$ | $10$ | $\begin{aligned} & 11 \\ & 1 \mathrm{~B} \end{aligned}$ | $\begin{aligned} & 12 \\ & 2 B \end{aligned}$ | $\begin{gathered} 13 \\ \hline \text { A1 } \\ \text { A6.9815 } \end{gathered}$ | $\underset{\substack{\text { Si.os5 }}}{14}$ |  | $\underset{\substack{16 \\ \hline \mathbf{3 2} 266}}{16}$ |  | $\begin{array}{\|c\|c} 18 \\ \text { Ar } \\ \text { 39.948 } \end{array}$ |
| $\begin{gathered} 19 \\ \text { K } \\ \text { 30.093 } \end{gathered}$ | $\begin{gathered} 20 \\ \mathrm{Ca} \end{gathered}$ | $\begin{gathered} 21 \\ \hline \text { Sc } \\ 4.9559 \end{gathered}$ | $\begin{gathered} \text { 22 } \\ \substack{\text { Ti } \\ 4788} \end{gathered}$ | $\begin{gathered} { }_{2}^{23} \\ \mathrm{~V}, 9415 \end{gathered}$ | $\begin{gathered} { }^{24} \\ \mathrm{Cr} \\ \mathrm{Cl}, 9961 \end{gathered}$ | $\begin{gathered} 25 \\ M n \end{gathered}$ | $\begin{gathered} 26 \\ \mathrm{Fe} \\ 55.847 \\ \hline \end{gathered}$ | $\begin{gathered} { }^{27} \\ \mathrm{Cs}, 9332 \end{gathered}$ | $\begin{gathered} \stackrel{28}{{ }_{2}^{2}} \\ \mathrm{si} .693 \end{gathered}$ | $\begin{gathered} 29 \\ \mathrm{Cu} \end{gathered}$ | $\begin{gathered} 30 \\ \text { Zn } \\ 65.39 \end{gathered}$ | $\begin{gathered} 31 \\ \mathrm{Ga} \\ \end{gathered}$ | $\begin{aligned} & 32 \\ & \mathrm{Ge} \end{aligned}$ ${ }_{72,61}$ | $\begin{gathered} 33 \\ \text { As } \\ 74.9216 \end{gathered}$ | $\begin{gathered} 34 \\ \begin{array}{c} 34 \\ \text { Se } \end{array} \\ \hline \end{gathered}$ | $\begin{gathered} 35 \\ \text { Br } \\ 79.904 \end{gathered}$ | $\begin{gathered} 36 \\ \hline \begin{array}{c} 36 \\ \text { Kr.s0 } \end{array} \end{gathered}$ |
| $\begin{gathered} 37 \\ \text { Rb } \\ \text { R5.4678 } \end{gathered}$ | $\begin{gathered} 38 \\ \hline \\ \hline 8 \\ \text { S7.62 } \end{gathered}$ | $\begin{gathered} 39 \\ \mathrm{ys} \\ \mathrm{~s} .959 \end{gathered}$ | $\begin{gathered} 40 \\ \mathrm{Zr}_{\mathrm{r}} \\ 91.24 \end{gathered}$ | $\begin{gathered} 41 \\ \mathrm{Nb} \\ 92.9064 \end{gathered}$ | $\begin{aligned} & 42 \\ & \begin{array}{l} 40 \\ \text { M5.94 } \end{array} \\ & \hline \end{aligned}$ | $\begin{aligned} & 43 \\ & \mathrm{Tc} \\ & \mathrm{Tc} \\ & \hline(\mathrm{ss}) \end{aligned}$ | $\begin{gathered} 44 \\ \text { Ru } \\ 101.07 \\ \hline \end{gathered}$ | $\begin{gathered} 45 \\ \text { Rh } \\ \text { R20.906 } \end{gathered}$ | $\begin{gathered} 46 \\ \begin{array}{c} \text { Pd } \\ 106.42 \end{array} \end{gathered}$ | $\begin{gathered} 47 \\ \text { Ag } \\ 107868 \end{gathered}$ | $\begin{gathered} { }_{c}^{48}{ }_{4}^{\mathrm{CD}} \\ 112.41 \end{gathered}$ | $\begin{array}{\|c\|c\|} \hline \text { In } \\ \text { In } \\ 14,818 \\ \hline \end{array}$ | $\begin{gathered} 50 \\ \text { Sn } \\ \text { nis.710 } \end{gathered}$ | $\begin{array}{\|c\|} \hline 51 \\ \hline \text { Sb } \\ \text { 121.557 } \\ \hline \end{array}$ | $\begin{gathered} 52 \\ \text { Te } \\ 127.60 \\ \hline \end{gathered}$ | $\begin{gathered} 53 \\ \text { I2 } \\ 126.904 \\ \hline \end{gathered}$ | $\begin{gathered} 54 \\ \text { Ye } \\ 131.29 \\ \hline \end{gathered}$ |
| $\begin{gathered} 55 \\ \text { Cs } \\ 132.05 \end{gathered}$ | $\begin{gathered} 56 \\ \text { 5a } \\ 137.327 \\ \hline \end{gathered}$ | $\begin{array}{\|c\|} \hline 57 \\ \begin{array}{c} 52 \\ \text { HLa } \\ \text { 139.966 } \end{array} \\ \hline \end{array}$ | $\begin{array}{\|c\|c\|} \hline 72 \\ \text { Hf } \\ 178.49 \\ \hline \end{array}$ | $\begin{gathered} 73 \\ \mathrm{Ta} \\ \text { 180.948 } \end{gathered}$ | $\begin{gathered} 74 \\ 18 . \\ 183.84 \end{gathered}$ | $\begin{gathered} 75 \\ \text { Re } \\ 186.207 \\ \hline \end{gathered}$ | $\begin{gathered} 76 \\ \text { 76 } \\ 190.23 \\ \hline \end{gathered}$ | $\begin{gathered} 77 \\ \text { Ir } \\ 192.22 \end{gathered}$ | $\begin{gathered} 78 \\ \text { Pt } \\ \text { P65.08 } \end{gathered}$ | $\begin{gathered} 79 \\ \text { Au } \\ 196.967 \end{gathered}$ | $\begin{gathered} 80 \\ { }^{80} \\ \text { 20.59 } \end{gathered}$ | $\begin{gathered} 81 \\ \text { 81 } \\ 204.383 \\ \hline \end{gathered}$ | $\begin{aligned} & 82 \\ & \mathrm{~Pb} \\ & 207.2 \end{aligned}$ | $\begin{array}{\|c} 83 \\ 8 i \\ \text { Bis.so } \\ \hline \end{array}$ | $\begin{aligned} & 84 \\ & \begin{array}{c} 80 \\ \text { Po } \\ (209) \end{array} \end{aligned}$ | $\begin{array}{\|c} 85 \\ \text { At } \\ \text { A10) } \end{array}$ | $\begin{aligned} & 86 \\ & \text { Rn } \\ & (222) \end{aligned}$ |
| $\begin{gathered} 87 \\ \hline \begin{array}{c} \mathrm{Fr} \\ \text { (223) } \\ \hline \end{array} \\ \hline \end{gathered}$ | $\begin{array}{\|c} 88 \\ \text { Ra } \\ \text { R26.025 } \\ \hline \end{array}$ | $\begin{gathered} 89 \\ \begin{array}{c} 8 \mathrm{Ac} \\ \text { TA7.a28 } \\ \hline \end{array} \\ \hline \end{gathered}$ | $\begin{aligned} & \left.1 \begin{array}{l} 104 \\ R 4 \\ \text { R } \\ (2611 \end{array}\right) \end{aligned}$ | $\begin{aligned} & 105 \\ & \begin{array}{l} \text { Db } \\ (262) \end{array} \end{aligned}$ | $\begin{gathered} 106 \\ \begin{array}{c} 106 \\ \text { (2660 } \end{array} \end{gathered}$ | $\begin{aligned} & 107 \\ & \hline 8 \mathrm{Bh} \\ & \text { (2664) } \end{aligned}$ | $\begin{aligned} & 108 \\ & \mathrm{Hs} \\ & (277) \end{aligned}$ | $\begin{aligned} & 109 \\ & \mathrm{Mt} \\ & (268) \end{aligned}$ | $\begin{array}{\|c\|} 110 \\ \text { Ds } \\ (271) \end{array}$ | $\begin{aligned} & 111 \\ & \mathbf{R g}_{2} \\ & (272) \end{aligned}$ |  |  |  |  |  |  |  |


| *Lanthanide series | $\begin{gathered} 58 \\ \mathrm{Ce} \\ 140.115 \end{gathered}$ | $\begin{gathered} 59 \\ \mathrm{Pr} \\ 140.908 \end{gathered}$ | $\begin{gathered} 60 \\ \mathrm{Nd} \\ 144.24 \end{gathered}$ | $\begin{gathered} 61 \\ \mathrm{Pm} \\ (145) \end{gathered}$ | $\begin{gathered} 62 \\ \mathrm{Sm} \\ 150.36 \end{gathered}$ | $\begin{gathered} 63 \\ \text { Eu } \\ 151.965 \end{gathered}$ | $\begin{gathered} 64 \\ \text { Gd } \\ 157.25 \end{gathered}$ | $\begin{gathered} 65 \\ \mathrm{~Tb} \\ 158.925 \end{gathered}$ | $\begin{gathered} 66 \\ \text { Dy } \\ 162.50 \end{gathered}$ | $\begin{gathered} 67 \\ \text { Ho } \\ 164.930 \end{gathered}$ | $\begin{gathered} 68 \\ \mathrm{Er} \\ 167.26 \end{gathered}$ | $\begin{gathered} 69 \\ \mathrm{Tm} \\ 168.934 \end{gathered}$ | $\begin{gathered} 70 \\ \mathrm{Yb} \\ 173.04 \end{gathered}$ | $\begin{gathered} 71 \\ \mathrm{Lu} \\ 174.967 \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| ${ }^{\dagger}$ Actinide series | $\begin{gathered} 90 \\ \text { Th } \\ 232.038 \end{gathered}$ | $\begin{gathered} 91 \\ \mathrm{~Pa} \\ 231.036 \end{gathered}$ | $\begin{gathered} 92 \\ \mathbf{U} \\ 238.029 \end{gathered}$ | $\begin{gathered} 93 \\ \mathrm{~Np} \\ 237.048 \end{gathered}$ | $\begin{aligned} & 94 \\ & \mathrm{Pu} \\ & (244) \end{aligned}$ | $\begin{aligned} & 95 \\ & \mathrm{Am} \\ & (243) \end{aligned}$ | $\begin{aligned} & 96 \\ & \mathrm{Cm} \\ & (247) \end{aligned}$ | 97 Bk <br> (247) | $\begin{gathered} 98 \\ \text { (251) } \end{gathered}$ | $\begin{gathered} 99 \\ \text { Es } \\ \text { (252) } \end{gathered}$ | $\begin{aligned} & 100 \\ & \text { Fm } \\ & (257) \end{aligned}$ | 101 <br> Md <br> (258) | $\begin{aligned} & 102 \\ & \text { No } \\ & \text { (259) } \end{aligned}$ | $\begin{gathered} 103 \\ \mathbf{L r} \\ (262) \end{gathered}$ |

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