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Worksheet of Directed Work in Atomic Physics

Exercice 1 : Theoretical Analysis of the Model

1. **Derivation of Angular Momentum Quantization :**
   Starting from Bohr's stability condition $\frac{Ze^2}{4\pi\varepsilon_0 r^2} = \frac{mv^2}{r}$ and the quantization condition $mvr = n\frac{h}{2\pi}$, demonstrate that the radius of the orbit is given by :
   $$r_n = \frac{\varepsilon_0 h^2 n^2}{\pi m_e e^2}$$
2. **Total Energy :**
   Express the total energy E_n of an electron in a hydrogen-like ion of atomic number Z as a function of n and Z. Provide a physical justification for why the energy is negative.

3.) **Wavelength and Frequency Calculations :**
   For the hydrogen atom :
   (a) Calculate the wavelength (in nm) and frequency (in Hz) of the photon emitted during the transition $n = 4 \rightarrow n = 2$.
   (b) Determine the region of the electromagnetic spectrum for this radiation.
   (c) Calculate the energy of this transition in joules and electronvolts.

4.) **Absorption vs Emission :**
   A hydrogen atom in its ground state absorbs a photon of wavelength 97.3 nm.
   (a) Calculate the energy of the absorbed photon.
   (b) To which energy level is the electron excited ?
   (c) What are the possible wavelengths of photons that could be emitted when the electron returns to the ground state ?

5.) **Series Limit Calculations :**
   (a) Calculate the shortest wavelength in the Balmer series (transition $n = \infty \rightarrow n = 2$).
   (b) Calculate the longest wavelength in the Paschen series (transition $n = 4 \rightarrow n = 3$).
   (c) Determine which of these two photons is more energetic.

Exercie 2 : Application to Hydrogen-like Ions

The He^+ ion (Z=2) and Li^{2+} ion (Z=3) are important hydrogen-like systems in medical physics.

1. **Energy Transitions :**
   Compare the energies of the photons emitted during the $n = 3 \rightarrow n = 2$ transition for :
   — The hydrogen atom (Z=1)
   — The He^+ ion (Z=2)
   — The Li^{2+} ion (Z=3)
   What pattern do you observe ? Generalize for a hydrogen-like ion of charge Z.
2. **Limit Wavelength :**
   For the He^+ ion, calculate the wavelength of the photon emitted during the transition $n = \infty \rightarrow n = 2$. In which region of the electromagnetic spectrum does it lie ?

Solution de l'exercice 1 : Analyse Théorique du Modèle

1) **Dérivation de la Quantification du Moment Cinétique :**

En partant de la condition de stabilité de Bohr $\dfrac{Ze^2}{4\pi\varepsilon_0 r^2} = \dfrac{mv^2}{r}$ et de la condition de quantification $mvr = n\dfrac{h}{2\pi}$, démontrez que le rayon de l'orbite est donné par : $r_n = \dfrac{\varepsilon_0 h^2 n^2}{\pi m_e e^2}$

Exprimez l'énergie totale E_n d'un électron dans l'atome d'hydrogène de fonction de n et Z. Donnez une justification physique expliquant pourquoi l'énergie est négative.

Solution

a) On part des deux équations fondamentales :

$$\text{Condition de stabilité :} \quad \frac{Ze^2}{4\pi\varepsilon_0 r^2} = \frac{mv^2}{r} \tag{1}$$

$$\text{Condition de quantification :} \quad mvr = n\frac{h}{2\pi} \tag{2}$$

Exprimer v à partir de l'équation (2)

$$v = \frac{nh}{2\pi mr}$$

Substituer dans l'équation (1)

$$\frac{Ze^2}{4\pi\varepsilon_0 r^2} = \frac{m}{r}\left(\frac{nh}{2\pi mr}\right)^2 \Rightarrow \frac{Ze^2}{4\pi\varepsilon_0 r^2} = \frac{n^2h^2}{4\pi^2 mr^3}$$

Isoler r

$$r = \frac{n^2h^2}{4\pi^2 m} \times \frac{4\pi\varepsilon_0}{Ze^2} \Rightarrow \boxed{r_n = \frac{\varepsilon_0 h^2 n^2}{\pi m_e e^2 Z}} \tag{3}$$

b) Énergie totale E_n :

$$E_n = E_c + E_p = \frac{mv^2}{2} - \frac{Ze^2}{4\pi\varepsilon_0 r_n}$$

Avec la condition du mouvement circulaire de l'eq (1) ça donne :

$$\frac{Ze^2}{4\pi\varepsilon_0 r} = mv^2$$

Donc :

$$E_n = \frac{Ze^2}{8\pi\varepsilon_0 r_n} - \frac{Ze^2}{4\pi\varepsilon_0 r_n} = -\frac{Ze^2}{8\pi\varepsilon_0 r_n}$$

En substituant le rayon quantifié de l'eq (3) dans l'expression de l'énergie :

$$E_n = -\frac{Ze^2}{8\pi\varepsilon_0} \cdot \frac{1}{r_n} = -\frac{Ze^2}{8\pi\varepsilon_0} \cdot \frac{\pi m_e e^2 Z}{\varepsilon_0 h^2 n^2}$$

Résultat final :

$$E_n = -\frac{m_e Z^2 e^4}{8\varepsilon_0^2 h^2 n^2}$$

c) Pourquoi l'énergie est-elle négative ?

— **Zéro à l'infini :** L'énergie est nulle quand l'électron est très loin

— **Attraction :** L'électron est attiré par le noyau, donc son énergie baisse (devient négative)

— **Énergie de liaison :** $|E_n|$ = énergie nécessaire pour arracher l'électron

— **Stabilité :** $E_n < 0$ signifie que l'électron est lié au noyau

Plus E_n est négatif, plus l'électron est fortement lié.

2) **Calculs de Longueur d'Onde et Fréquence :**
Pour l'atome d'hydrogène :
   (a) Calculez la longueur d'onde (en nm) et la fréquence (en Hz) du photon émis lors de la transition $n = 4 \rightarrow n = 2$.
   (b) Déterminez la région du spectre électromagnétique de ce rayonnement.
   (c) Calculez l'énergie de cette transition en joules et en électronvolts.

Solution

2) **Calculs de Longueur d'Onde et Fréquence :**
Pour l'atome d'hydrogène :
   (a) **Calcul de la longueur d'onde et fréquence pour la transition** $n = 4 \rightarrow n = 2$
   On utilise la formule de Rydberg pour l'atome d'hydrogène ($Z = 1$) :

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

   où $R_H = 1,097 \times 10^7 \text{ m}^{-1}$, $n_1 = 2$, $n_2 = 4$

$$\frac{1}{\lambda} = 1,097 \times 10^7 \left(\frac{1}{2^2} - \frac{1}{4^2} \right) = 1,097 \times 10^7 \left(\frac{1}{4} - \frac{1}{16} \right)$$

$$\frac{1}{\lambda} = 1,097 \times 10^7 \left(\frac{4}{16} - \frac{1}{16} \right) = 1,097 \times 10^7 \times \frac{3}{16}$$

$$\frac{1}{\lambda} = 1,097 \times 10^7 \times 0,1875 = 2,0569 \times 10^6 \text{ m}^{-1}$$

$$\lambda = \frac{1}{2,0569 \times 10^6} = 4,86 \times 10^{-7} \text{ m} = 486 \text{ nm}$$

   Fréquence :

$$\nu = \frac{c}{\lambda} = \frac{3,00 \times 10^8}{4,86 \times 10^{-7}} = 6,17 \times 10^{14} \text{ Hz}$$

$$\boxed{\lambda = 486 \text{ nm}} \quad \boxed{\nu = 6,17 \times 10^{14} \text{ Hz}}$$

   (b) **Région du spectre électromagnétique**
   La longueur d'onde de 486 nm se situe dans le domaine :

   Visible (bleu-vert)

   Plus précisément dans la série de Balmer.
   (c) **Énergie de la transition**
   En joules :

$$E = h\nu = (6,626 \times 10^{-34}) \times (6,17 \times 10^{14}) = 4,09 \times 10^{-19} \text{ J}$$

   En électronvolts :

$$E = \frac{4,09 \times 10^{-19}}{1,602 \times 10^{-19}} = 2,55 \text{ eV}$$

   Vérification par la formule des niveaux d'énergie :

$$E = E_2 - E_4 = \left(-\frac{13,6}{4} \right) - \left(-\frac{13,6}{16} \right) = -3,4 - (-0,85) = -2,55 \text{ eV}$$

   La valeur absolue confirme notre résultat.

$$\boxed{E = 4,09 \times 10^{-19} \text{ J}} \quad \boxed{E = 2,55 \text{ eV}}$$

3) **Absorption vs Émission :** Un atome d'hydrogène dans son état fondamental absorbe un photon de longueur d'onde 97,3 nm.
   (a) Calculez l'énergie du photon absorbé.
   (b) Vers quel niveau d'énergie l'électron est-il excité ?
   (c) Quelles sont les longueurs d'onde possibles des photons du retourne à l'état fondamental ?

Solution

(a) **Énergie du photon absorbé**

$$E = \frac{hc}{\lambda} = \frac{(6,626 \times 10^{-34}) \times (3,00 \times 10^{8})}{97,3 \times 10^{-9}} = \frac{1,9878 \times 10^{-25}}{9,73 \times 10^{-8}} = 2,042 \times 10^{-18}\ \text{J}$$

En électronvolts :

$$E = \frac{2,042 \times 10^{-18}}{1,602 \times 10^{-19}} = 12,75\ \text{eV}$$

(b) **Niveau d'énergie d'excitation**

L'énergie des niveaux de l'hydrogène est donnée par :

$$E_n = -\frac{13,6}{n^2}\ \text{eV}$$

L'électron part de l'état fondamental $n = 1$ ($E_1 = -13,6$ eV) et absorbe 12,75 eV :

$$E_{\text{final}} = E_1 + E_{\text{photon}} = -13,6 + 12,75 = -0,85\ \text{eV}$$

On cherche n tel que :

$$-\frac{13,6}{n^2} = -0,85 \quad \Rightarrow \quad n^2 = \frac{13,6}{0,85} = 16 \quad \Rightarrow \quad n = 4$$

L'électron est excité vers le niveau $n = 4$.

(c) **Longueurs d'onde possibles lors du retour à l'état fondamental**

L'électron est excité vers le niveau $n = 4$. ilpeut revenir à l'état fondamental ($n = 1$) par différentes transitions :

Transition directe : $4 \to 1$

$$\frac{1}{\lambda} = R_H \left(\frac{1}{1^2} - \frac{1}{4^2}\right) = 1{,}097 \times 10^7 \left(1 - \frac{1}{16}\right) = 1{,}028 \times 10^7\ \text{m}^{-1} \Rightarrow \lambda = 97{,}3\ \text{nm}$$

Transitions indirectes :

— $4 \to 2 \to 1$:

$$4 \to 2 : \frac{1}{\lambda} = R_H \left(\frac{1}{4} - \frac{1}{16}\right) = 1{,}097 \times 10^7 \times \frac{3}{16} \Rightarrow \lambda = 486\ \text{nm}$$

$$2 \to 1 : \frac{1}{\lambda} = R_H \left(1 - \frac{1}{4}\right) = 1{,}097 \times 10^7 \times \frac{3}{4} \Rightarrow \lambda = 121{,}6\ \text{nm}$$

— $4 \to 3 \to 1$:

$$4 \to 3 : \frac{1}{\lambda} = R_H \left(\frac{1}{9} - \frac{1}{16}\right) = 1{,}097 \times 10^7 \times \frac{7}{144} \Rightarrow \lambda = 1875\ \text{nm}$$

$$3 \to 1 : \frac{1}{\lambda} = R_H \left(1 - \frac{1}{9}\right) = 1{,}097 \times 10^7 \times \frac{8}{9} \Rightarrow \lambda = 102{,}6\ \text{nm}$$

— $4 \to 3 \to 2 \to 1$:

$$4 \to 3 : \lambda = 1875\ \text{nm} \quad \text{(déjà calculé)}$$

$$3 \to 2 : \frac{1}{\lambda} = R_H \left(\frac{1}{4} - \frac{1}{9}\right) = 1{,}097 \times 10^7 \times \frac{5}{36} \Rightarrow \lambda = 656\ \text{nm}$$

$$2 \to 1 : \lambda = 121{,}6\ \text{nm} \quad \text{(déjà calculé)}$$

Longueurs d'onde possibles (sans doublons) :

$$\boxed{97{,}3\ \text{nm},\ 102{,}6\ \text{nm},\ 121{,}6\ \text{nm},\ 486\ \text{nm},\ 656\ \text{nm},\ 1875\ \text{nm}}$$

Séries spectrales :

— Série de Lyman (vers $n = 1$) : 97,3, 102,6, 121,6 nm
— Série de Balmer (vers $n = 2$) : 486, 656 nm
— Série de Paschen (vers $n = 3$) : 1875 nm

4) **Calculs de Limite de Série :**
   (a) Calculez la longueur d'onde la plus courte dans la série de Balmer (transition $n = \infty \to n = 2$).
   (b) Calculez la longueur d'onde la plus longue dans la série de Paschen (transition $n = 4 \to n = 3$).
   (c) Déterminez lequel de ces deux photons est le plus énergétique.

Solution

Calculs de Limite de Série :

(a) **Longueur d'onde la plus courte dans la série de Balmer ($n = \infty \to n = 2$)**
Formule de Rydberg :

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

Pour $n_1 = 2$, $n_2 = \infty$:

$$\frac{1}{\lambda} = R_H \left(\frac{1}{2^2} - \frac{1}{\infty} \right) = R_H \left(\frac{1}{4} - 0 \right) = \frac{R_H}{4} \Rightarrow \lambda = \frac{4}{1,097 \times 10^7} = 3,645 \times 10^{-7} \text{ m} = 364,5 \text{ nm}$$

(b) **Longueur d'onde la plus longue dans la série de Paschen ($n = 4 \to n = 3$)**
Pour la série de Paschen, $n_1 = 3$. La transition la moins énergétique est $n = 4 \to n = 3$:

$$\frac{1}{\lambda} = R_H \left(\frac{1}{3^2} - \frac{1}{4^2} \right) = R_H \left(\frac{1}{9} - \frac{1}{16} \right) = 5,332 \times 10^5 \text{ m}^{-1} \Rightarrow \lambda = \frac{1}{5,332 \times 10^5} = 1875 \text{ nm}$$

(c) **Comparaison d'énergie des photons**
L'énergie d'un photon est inversement proportionnelle à sa longueur d'onde :

$$E = \frac{hc}{\lambda}$$

Photon Balmer : $\lambda = 364,5$ nm

$$E_B = \frac{1240}{\lambda(\text{nm})} = \frac{1240}{364,5} = 3,40 \text{ eV}$$

Photon Paschen : $\lambda = 1875$ nm

$$E_P = \frac{1240}{1875} = 0,661 \text{ eV}$$

Comparaison directe :

$$\frac{E_B}{E_P} = \frac{3,40}{0,661} \approx 5,14$$

Conclusion : Le photon de la limite de Balmer (3,40 eV) est environ 5 fois plus énergétique que celui de la transition Paschen la plus longue (0,661 eV).

Solution de l'exercice 2 : Application aux Ions Hydrogénoïdes

Les ions He^+ (Z=2) et Li^{2+} (Z=3) sont des systèmes hydrogenoïdes importants en physique médicale.

1. **Transitions Énergétiques :**
   Comparez les énergies des photons émis lors de la transition $n = 3 \to n = 2$ pour :
   - L'atome d'hydrogène (Z=1)
   - L'ion He^+ (Z=2)
   - L'ion Li^{2+} (Z=3)

   Quel motif observez-vous ? Généralisez pour un ion hydrogenoïde de charge Z.

Solution

1. **Transitions Énergétiques :** $n = 3 \to n = 2$
   Pour un ion hydrogénoïde, l'énergie des niveaux est :

$$E_n = -\frac{Z^2 \cdot 13,6}{n^2} \text{ eV}$$

L'énergie de la transition $n = 3 \to n = 2$ est :

$$\Delta E = E_2 - E_3 = -Z^2 \cdot 13,6 \left(\frac{1}{2^2} - \frac{1}{3^2}\right)$$

$$\Delta E = -Z^2 \cdot 13,6 \left(\frac{1}{4} - \frac{1}{9}\right) = -Z^2 \cdot 13,6 \cdot \frac{5}{36}$$

$$\Delta E = Z^2 \cdot 1,889 \text{ eV}$$

Calculs pour chaque ion :

- **Hydrogène (Z=1) :**

$$\Delta E = (1)^2 \cdot 1,889 = 1,889 \text{ eV}$$

$$\lambda = \frac{1240}{1,889} = 656 \text{ nm}$$

- **He^+ (Z=2) :**

$$\Delta E = (2)^2 \cdot 1,889 = 4 \cdot 1,889 = 7,556 \text{ eV}$$

$$\lambda = \frac{1240}{7,556} = 164 \text{ nm}$$

- **Li^{2+} (Z=3) :**

$$\Delta E = (3)^2 \cdot 1,889 = 9 \cdot 1,889 = 17,00 \text{ eV}$$

$$\lambda = \frac{1240}{17,00} = 72,9 \text{ nm}$$

Résumé :

$\boxed{\text{H : 1,89 eV (656 nm)}}$ $\boxed{\text{He}^+ \text{ : 7,56 eV (164 nm)}}$ $\boxed{\text{Li}^{2+} \text{ : 17,0 eV (72,9 nm)}}$

Motif observé : L'énergie de la transition est proportionnelle à Z^2

$$\Delta E \propto Z^2$$

Généralisation : Pour un ion hydrogénoïde de charge Z :

$$\boxed{\Delta E_{n_1 \to n_2} = Z^2 \cdot 13,6 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) \text{ eV}}$$

2. **Longueur d'Onde Limite :** Pour l'ion He^+, calculez la longueur d'onde du photon émis lors de la transition $n = \infty \to n = 2$. Dans quelle région du spectre électromagnétique se situe-t-elle ?

Solution

a) **Longueur d'Onde Limite pour He^+ ($n = \infty \to n = 2$)**
Pour He^+ (Z=2), la transition $n = \infty \to n = 2$:

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

$$\frac{1}{\lambda} = (2)^2 \cdot 1,097 \times 10^7 \left(\frac{1}{2^2} - \frac{1}{\infty} \right)$$

$$\frac{1}{\lambda} = 4 \cdot 1,097 \times 10^7 \cdot \frac{1}{4} = 1,097 \times 10^7 \text{ m}^{-1}$$

$$\lambda = \frac{1}{1,097 \times 10^7} = 9,116 \times 10^{-8} \text{ m}$$

$$\boxed{\lambda = 91,16 \text{ nm}}$$

Région du spectre :

Ultraviolet lointain

Vérification par l'énergie :

$$E = \frac{1240}{91,16} = 13,6 \text{ eV} \quad \text{(énergie d'ionisation depuis n=2 pour He}^+\text{)}$$

Exercice : In medicine, understanding matter-radiation interactions is fundamental, particularly for medical imaging (CT scanners, MRI) and radiotherapy. The Bohr model, although simplified, provides a foundational understanding of light emission and absorption by atoms.

Constants and Data

— Rydberg constant for hydrogen : $R_H = 1.097 \times 10^7 \text{ m}^{-1}$
— Planck's constant : $h = 6.626 \times 10^{-34} \text{ J} \cdot \text{ s}$
— Speed of light in a vacuum : $c = 3.00 \times 10^8 \text{ m} \cdot \text{ s}^{-1}$
— $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$
— $1 \text{ nm} = 10^{-9} \text{ m}$

Part 1 : Course Review Questions

1) State the two main postulates of the Bohr model for the hydrogen atom.
2) What is a **photon** ? What is the relationship between its energy E and the wavelength λ of the associated radiation ?
3) Define what an **energy level** is for an electron in an atom. What happens when the electron moves from a level n_i to a level n_f where $n_f < n_i$?

Part 2 : Numerical Application (The Balmer Series) The Balmer series corresponds to all electronic transitions where the electron falls to the energy level $n_f = 2$. This series produces lines in the visible region of the electromagnetic spectrum.

a) **Calculating a wavelength :**
   An excited electron in a hydrogen atom relaxes by moving from the level $n_i = 3$ to the level $n_f = 2$.
   1) Calculate the wavelength λ (in nm) of the photon emitted during this transition. Use the Rydberg formula :
   $$\frac{1}{\lambda} = R_H \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$
   2) Is this emitted radiation visible to the naked eye ? Justify your answer. (The visible range extends approximately from 400 nm to 800 nm).
b) **Calculating an energy :**
   1) Calculate the energy (in Joules, then in electronvolts) of the photon emitted during the transition $n_i = 4 \rightarrow n_f = 2$.
   2) Compare this energy to that of the transition $n_i = 3 \rightarrow n_f = 2$. Which one is more energetic ? Why is this logical ?

Part 3 : Synthesis Problem (Link to Physiology) Hemoglobin, the protein that transports oxygen in the blood, has an active part called "heme". At the center of the heme is an iron atom (Fe^{2+}). For simplification purposes, we can model an electron of this ferrous ion as if it were in a "Bohr atom" where the energy of a level n is given by
$$E_n = -\frac{13.6}{n^2} \text{ eV}.$$

a) Calculate the energies of the levels $n = 1$, $n = 2$, and $n = 3$ for this electron.
b) When blood is well-oxygenated (arterial), the electron is in its ground state ($n = 1$). When the blood is low in oxygen (venous), this electron can absorb a photon with a wavelength $\lambda = 430$ nm and move to an excited state.
   1) Calculate the energy (in eV) of the photon with a wavelength of 430 nm.
   2) Considering the levels calculated in question 1, to which level n was this electron excited ? Justify your reasoning.
   3) It is this absorption of light that gives deoxygenated blood its **bluish-violet** color (observable in veins under the skin), while oxygenated blood, which does not absorb in the visible range, is red. Explain this phenomenon in one sentence, linking it to the Bohr model.

Contexte : En médecine, la compréhension des interactions entre la matière et les rayonnements est fondamentale, particulièrement pour l'imagerie médicale (scanners, IRM) et la radiothérapie. Le modèle de Bohr, bien que simplifié, permet de saisir les bases de l'émission et de l'absorption de la lumière par les atomes.

Partie 1 : Questions de Cours

a) Énoncez les deux postulats principaux du modèle de Bohr pour l'atome d'hydrogène.
b) Qu'est-ce qu'un **photon** ? Quelle est la relation entre son énergie E et la longueur d'onde λ de la radiation associée ?
c) Définissez ce qu'est un **niveau d'énergie** pour un électron dans un atome. Que se passe-t-il lorsque l'électron passe d'un niveau n_i à un niveau n_f où $n_f < n_i$?

Partie 2 : Application Numérique (Série de Balmer)

La série de Balmer correspond à toutes les transitions électroniques où l'électron arrive sur le niveau d'énergie $n_f = 2$. Cette série produit des raies dans le domaine visible du spectre électromagnétique.

a) **Calcul d'une longueur d'onde :**
Un électron excité dans un atome d'hydrogène se désexcite en passant du niveau $n_i = 3$ au niveau $n_f = 2$.
   1) Calculez la longueur d'onde λ (en nm) du photon émis lors de cette transition. Utilisez la formule de Rydberg :
$$\frac{1}{\lambda} = R_H \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$
   2) Cette radiation émise est-elle visible à l'œil nu ? Justifiez votre réponse. (Le domaine visible s'étend approximativement de 400 nm à 800 nm).

b) **Calcul d'une énergie :**
   (1) Calculez l'énergie (en Joules, puis en électronvolts) du photon émis lors de la transition $n_i = 4 \rightarrow n_f = 2$.
   (2) Comparez cette énergie à celle de la transition $n_i = 3 \rightarrow n_f = 2$. Laquelle est la plus énergétique ? Pourquoi est-ce logique ?

Partie 3 : Problème de Synthèse (Lien avec la Physiologie)

L'hémoglobine, la protéine qui transporte l'oxygène dans le sang, possède une partie active appelée "hème". Au centre de l'hème se trouve un atome de fer (${Fe_2}^+$). Pour simplifier, on peut modéliser un électron de cet ion ferreux comme étant dans un "atome de Bohr" où l'énergie d'un niveau n est donnée par

$$E_n = -\frac{13,6}{n^2} \text{ eV}.$$

a) Calculez les énergies des niveaux $n = 1$, $n = 2$ et $n = 3$ pour cet électron.
b) Lorsque le sang est bien oxygéné (artériel), l'électron est dans son état fondamental ($n = 1$). Lorsque le sang est pauvre en oxygène (veineux), cet électron peut absorber un photon de longueur d'onde $\lambda = 430$ nm et passer à un niveau excité.
   (1) Calculez l'énergie (en eV) du photon de longueur d'onde 430 nm.
   (2) En considérant les niveaux calculés à la question 1, vers quel niveau n cet électron a-t-il été excité ? Justifiez votre raisonnement.
   (3) C'est cette absorption de lumière qui donne au sang désoxygéné sa couleur **bleu-violet** (observable dans les veines sous la peau), tandis que le sang oxygéné, qui n'absorbe pas dans le visible, est rouge. Expliquez ce phénomène en une phrase en lien avec le modèle de Bohr.

Données et Constantes :

— Constante de Rydberg pour l'hydrogène : $R_H = 1{,}097 \times 10^7$ m^{-1}
— Constante de Planck : $h = 6{,}626 \times 10^{-34}$ J · s
— Célérité de la lumière dans le vide : $c = 3{,}00 \times 10^8$ m · s^{-1}
— 1 eV = $1{,}602 \times 10^{-19}$ J
— 1 nm = 10^{-9} m

1). The two main postulates of the Bohr model are :

A) Quantization of angular momentum and stationary orbits
B) Continuous emission and elliptical orbits
C) Uncertainty principle and wave-particle duality
D) Electron spin and Pauli exclusion
E) Constant electric field and absolute time

2). The Rydberg constant for hydrogen has the value :

A) $1.097 \times 10^7\, m^{-1}$
B) $6.626 \times 10^{-34}\, J \cdot s$
C) $3.00 \times 10^8\, m/s$
D) $9.11 \times 10^{-31}\, kg$
E) $1.602 \times 10^{-19}\, C$

3). The Rydberg formula is written as :

A) $\frac{1}{\lambda} = R_H \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$
B) $\lambda = R_H(n_i - n_f)$
C) $E = R_H \cdot h \cdot c$
D) $\frac{1}{\lambda} = R_H(n_i^2 - n_f^2)$
E) $\lambda = \frac{R_H}{n}$

4). A photon is defined as :

A) A quantum of light energy
B) A charged material particle
C) A mechanical wave
D) A free electron
E) A fast neutron

5). The relationship between energy and wavelength of a photon is :

A) $E = \frac{hc}{\lambda}$
B) $E = h\lambda$
C) $E = \frac{\lambda}{hc}$
D) $E = c\lambda$
E) $E = \frac{h}{\lambda c}$

6). Planck's constant has the value :

A) $6.626 \times 10^{-34}\, J \cdot s$
B) $1.097 \times 10^7\, m^{-1}$
C) $3.00 \times 10^8\, m/s$
D) $9.11 \times 10^{-31}\, kg$
E) $1.381 \times 10^{-23}\, J/K$

7). When an electron goes from n=3 to n=2 in the hydrogen atom :

A) It emits a photon
B) It absorbs a photon
C) The atom ionizes
D) The energy decreases
E) The spin changes

8). The Balmer series corresponds to transitions to :

A) n = 2
B) n = 1
C) n = 3
D) n = 4
E) n = 5

9). The speed of light in vacuum is :

A) $3.00 \times 10^8\, m/s$
B) $3.00 \times 10^6\, m/s$
C) $1.86 \times 10^8\, m/s$
D) $3.00 \times 10^{10}\, cm/s$
E) $2.99 \times 10^8\, m/s$

10). 1 electron-volt (eV) is equivalent to :

A) $1.602 \times 10^{-19}\, J$
B) $6.626 \times 10^{-34}\, J$
C) $1.097 \times 10^7\, J$
D) $3.00 \times 10^8\, J$
E) $9.11 \times 10^{-31}\, J$

11). For the transition n=3 → n=2, the wavelength is approximately :

A) 656 nm
B) 486 nm
C) 434 nm
D) 121 nm
E) 102 nm

12). The visible range extends approximately from :

A) 400 nm to 800 nm
B) 200 nm to 400 nm
C) 800 nm to 1 mm
D) 10 nm to 400 nm
E) 1 mm to 1 m

13). The energy of a level n in the hydrogen atom is given by :

A) $E_n = -\frac{13.6}{n^2}\, eV$
B) $E_n = +\frac{13.6}{n^2}\, eV$
C) $E_n = -13.6 \times n^2\, eV$
D) $E_n = \frac{hc}{n}\, eV$
E) $E_n = R_H \times n\, eV$

14). The ionization energy of the hydrogen atom is :

A) 13.6 eV
B) 3.4 eV
C) 1.5 eV
D) 0.85 eV
E) 10.2 eV

15). For n=1, the energy of the electron in the hydrogen atom is :

A) -13.6 eV
B) -3.4 eV
C) -1.5 eV
D) 0 eV

E) +13.6 eV

16). The Lyman series corresponds to transitions to :
A) n = 1
B) n = 2
C) n = 3
D) n = 4
E) n = 5

17). The lines of the Lyman series are located in :
A) The ultraviolet
B) The visible
C) The infrared
D) X-rays
E) Microwaves

18). For the transition n=2 $\rightarrow$ n=1, the energy of the emitted photon is :
A) 10.2 eV
B) 13.6 eV
C) 3.4 eV
D) 1.9 eV
E) 0.66 eV

19). The momentum of a photon is given by :
A) $p = \frac{h}{\lambda}$
B) $p = h\lambda$
C) $p = \frac{E}{c}$
D) $p = mc$
E) $p = \frac{hc}{\lambda}$

20). Bohr's quantization principle states that :
A) $mvr = n\frac{h}{2\pi}$
B) $E = nh\nu$
C) $p = \frac{h}{\lambda}$
D) $\Delta x \Delta p \geq \frac{h}{4\pi}$
E) $v = \frac{e^2}{2h\epsilon_0}$

21). For n=4 $\rightarrow$ n=2, the wavelength is approximately :
A) 486 nm
B) 656 nm
C) 434 nm
D) 410 nm
E) 397 nm

22). The energy of level n=3 in the hydrogen atom is :
A) -1.51 eV
B) -3.40 eV
C) -13.6 eV
D) -0.85 eV
E) -0.54 eV

23). The frequency of a photon is related to its wavelength by :
A) $\nu = \frac{c}{\lambda}$
B) $\nu = c\lambda$
C) $\nu = \frac{\lambda}{c}$
D) $\nu = \frac{hc}{\lambda}$
E) $\nu = \frac{E}{h}$

24). The principal quantum number n can take the values :
A) 1, 2, 3, ...
B) 0, 1, 2, 3, ...
C) -1, 0, +1
D) $\frac{1}{2}, 1, \frac{3}{2}, ...$
E) $0, \frac{1}{2}, 1, \frac{3}{2}, ...$

25). For the transition n=∞ $\rightarrow$ n=2, the photon energy is :
A) 3.40 eV
B) 13.60 eV
C) 1.51 eV
D) 0.85 eV
E) 10.20 eV

26). The limit of the Balmer series is at :
A) 364.6 nm
B) 656.3 nm
C) 121.6 nm
D) 486.1 nm
E) 434.0 nm

27). An electron-volt is the energy acquired by an electron :
A) Accelerated by a potential difference of 1 volt
B) At rest
C) In the ground state
D) At the speed of light
E) In a magnetic field of 1 tesla

28). The de Broglie wavelength for a particle is :
A) $\lambda = \frac{h}{p}$
B) $\lambda = \frac{p}{h}$
C) $\lambda = \frac{h}{E}$
D) $\lambda = \frac{E}{h}$
E) $\lambda = hc$

29). For n=5 $\rightarrow$ n=2, the energy of the emitted photon is :
A) 2.86 eV
B) 2.55 eV
C) 1.89 eV
D) 0.97 eV

E) 0.54 eV

30). The radius of the Bohr orbit for the ground state is :
A) 0.529 Å
B) 1.058 Å
C) 2.116 Å
D) 0.265 Å
E) 1.000 Å

31). The Paschen series corresponds to transitions to :
A) n = 3
B) n = 1
C) n = 2
D) n = 4
E) n = 5

32). The lines of the Paschen series are located in :
A) The infrared
B) The ultraviolet
C) The visible
D) X-rays
E) Radio waves

33). For the transition n=4 → n=3, the energy of the emitted photon is :
A) 0.66 eV
B) 1.89 eV
C) 2.55 eV
D) 0.85 eV
E) 1.51 eV

34). The Bohr model strictly applies to :
A) Hydrogen-like atoms
B) All atoms
C) Diatomic molecules
D) Crystalline solids
E) Atomic nuclei

35). The speed of the electron on the n=1 orbit is :
A) $\frac{c}{137}$
B) $\frac{c}{2}$
C) c
D) 2c
E) $\frac{c}{10}$

36). The angular momentum of the electron on the n=1 orbit is :
A) $\frac{h}{2\pi}$
B) h
C) 2h
D) $\frac{h}{4\pi}$
E) $\frac{3h}{2\pi}$

37). For a hydrogen-like atom of atomic number Z, the energy becomes :
A) $E_n = -\frac{13.6Z^2}{n^2}\,eV$
B) $E_n = -\frac{13.6}{Zn^2}\,eV$
C) $E_n = -\frac{13.6Z}{n^2}\,eV$
D) $E_n = -13.6Z^2\,eV$
E) $E_n = -\frac{Z^2}{n^2}\,eV$

38). The ionization energy of He^+ (Z=2) is :
A) 54.4 eV
B) 13.6 eV
C) 27.2 eV
D) 6.8 eV
E) 108.8 eV

39). The general Rydberg constant for a hydrogen-like atom is :
A) $R_Z = Z^2 R_H$
B) $R_Z = ZR_H$
C) $R_Z = \frac{R_H}{Z}$
D) $R_Z = R_H$
E) $R_Z = \frac{R_H}{Z^2}$

40). The main defect of the Bohr model is :
A) It only applies to hydrogen-like atoms
B) It poorly predicts line intensities
C) It doesn't account for spin
D) It violates the uncertainty principle
E) All of these answers

41). The selection rule for transitions in the Bohr model is :
A) Any Δn
B) $\Delta n = \pm 1$
C) $\Delta n = 0, \pm 1$
D) Only even Δn
E) Only odd Δn

42). For a 2 eV photon, the wavelength is approximately :
A) 620 nm
B) 310 nm
C) 1240 nm
D) 2480 nm
E) 155 nm

43). The kinetic energy of the electron on the n=1 orbit is :
A) 13.6 eV
B) -13.6 eV
C) 27.2 eV
D) -27.2 eV
E) 0 eV

44). The potential energy of the electron on the n=1 orbit is :
A) -27.2 eV

B) 27.2 eV
C) -13.6 eV
D) 13.6 eV
E) 0 eV

45). The ratio of the radii of orbits n=2 and n=1 is :
A) 4
B) 2
C) 1
D) 1/2
E) 1/4

46). The ratio of the speeds of orbits n=2 and n=1 is :
A) 1/2
B) 2
C) 1
D) 4
E) 1/4

47). The revolution frequency of the electron on n=1 is :
A) 6.58×10^{15} Hz
B) 3.29×10^{15} Hz
C) 1.64×10^{15} Hz
D) 8.22×10^{14} Hz
E) 4.11×10^{14} Hz

48). For the transition n=6 → n=2, the spectral series is :
A) Balmer
B) Lyman
C) Paschen
D) Brackett
E) Pfund

49). The maximum number of electrons in the n=3 shell is :
A) 18
B) 2
C) 8
D) 32
E) 50

50). The theory that replaced the Bohr model is :
A) Quantum mechanics
B) General relativity
C) Classical electrodynamics
D) Statistical mechanics
E) Field theory

51). The two main postulates of Bohr's model for the hydrogen atom are :
A) Electrons move in circular orbits and emit continuous radiation.
B) Electrons exist in stable orbits without radiating, and angular momentum is quantized.
C) Energy is quantized and electrons behave as waves.
D) Orbits are elliptical and energy decreases with time.
E) Electrons radiate energy constantly and orbits decay.

52). A photon is best described as :
A) A charged particle with mass.
B) A quantum of electromagnetic energy.
C) A sound wave packet.
D) A type of electron.
E) A magnetic monopole.

53). The relationship between a photon's energy E and its wavelength λ is :
A) $E = \dfrac{h}{c\lambda}$
B) $E = hc\lambda$
C) $E = \dfrac{hc}{\lambda}$
D) $E = \dfrac{\lambda}{hc}$
E) $E = h\lambda$

54). An energy level for an electron in an atom represents :
A) The speed of the electron in its orbit.
B) A stable state with definite energy where the electron can exist.
C) The distance from the nucleus.
D) The orbital shape parameter.
E) The magnetic moment orientation.

55). When an electron moves from level n_i to level n_f where $n_f < n_i$:
A) A photon is absorbed.
B) The atom becomes ionized.
C) A photon is emitted.
D) The electron gains energy.
E) The nucleus decays.

56). The Balmer series corresponds to transitions where the final level is :
A) n=1
B) n=2
C) n=3
D) n=4
E) n= ∞

57). For the transition $n_i = 3 \to n_f = 2$ in hydrogen, using Rydberg formula with $R_H = 1.097 \times 10^7$ m^{-1}, the wavelength is approximately :
A) 121.6 nm
B) 434 nm
C) 486 nm
D) 656 nm
E) 102.6 nm

58). The radiation from the $n = 3 \to n = 2$ transition :

A) Is in the ultraviolet region
B) Is in the infrared region
C) Is visible to the naked eye
D) Is an X-ray
E) Is a gamma ray

59). The visible range of the electromagnetic spectrum extends approximately from :

A) 200-500 nm
B) 300-600 nm
C) 400-800 nm
D) 500-1000 nm
E) 600-1200 nm

60). For the transition $n_i = 4 \to n_f = 2$, the energy of the emitted photon is :

A) Less energetic than $n = 3 \to n = 2$
B) More energetic than $n = 3 \to n = 2$
C) Equal to $n = 3 \to n = 2$
D) Cannot be compared
E) Exactly half of $n = 3 \to n = 2$

61). The energy difference between levels in hydrogen :

A) Increases as n increases
B) Decreases as n increases
C) Is constant for all transitions
D) Depends only on the nuclear charge
E) Is always zero

62). For the simplified iron atom model with $E_n = -\dfrac{13.6}{n^2}$ eV, the ground state energy (n=1) is :

A) 0 eV
B) -13.6 eV
C) -3.4 eV
D) -1.51 eV
E) +13.6 eV

63). For the same model, the energy of the n=2 level is :

A) -13.6 eV
B) -6.8 eV
C) -3.4 eV
D) -1.5 eV
E) 0 eV

64). A photon with wavelength 430 nm has energy approximately :

A) 1.88 eV
B) 2.88 eV
C) 3.88 eV
D) 4.88 eV
E) 5.88 eV

65). For the iron electron absorbing a 430 nm photon, the most likely excited level is :

A) n=2
B) n=3
C) n=4
D) n=5
E) n=6

66). The bluish-violet color of deoxygenated blood is due to :

A) Emission of blue light
B) Absorption of red light
C) Absorption of blue-green light
D) Reflection of all colors
E) Transmission of ultraviolet

67). Oxygenated blood appears red because :

A) It emits red light
B) It absorbs all colors except red
C) It reflects blue light
D) It contains iron in a different state that doesn't absorb visible light
E) It fluoresces in red

68). The Rydberg formula calculates :

A) Electron velocity
B) Orbital radius
C) Energy levels directly
D) Wavelength of emitted/absorbed radiation
E) Nuclear charge

69). In the Balmer series, the shortest wavelength corresponds to transition :

A) n=3→2
B) n=4→2
C) n=5→2
D) n=6→2
E) n=∞→2

70). The energy of a photon emitted in atomic transition depends on :

A) The mass of the electron only
B) The difference between initial and final energy levels
C) The orbital shape only
D) The magnetic field strength
E) The temperature of the atom

71). For medical imaging, understanding atomic transitions helps in :

A) Designing radiation detectors
B) Calculating drug dosages
C) Predicting chemical reactions
D) Determining blood pressure
E) Measuring body temperature

72). In radiotherapy, the Bohr model helps understand :

A) How radiation interacts with cancer cells at atomic level
B) How to perform surgery

C) How to diagnose infections
D) How to measure blood sugar
E) How to monitor heart rate

73). The principal quantum number n determines :
A) The electron spin only
B) The energy and size of the orbit
C) The nuclear composition
D) The chemical symbol
E) The atomic mass

74). When an electron is excited to a higher energy level :
A) The atom becomes ionized permanently
B) The atom must immediately emit radiation
C) The electron can stay there briefly before returning to lower level
D) The nucleus changes its charge
E) The atom becomes radioactive

75). The significance of negative energy values in atomic physics is that :
A) The electron has negative mass
B) The electron is bound to the nucleus
C) The atom is unstable
D) The energy is imaginary
E) The measurement is incorrect

76). In the Bohr model, the stability condition postulates that :
A) The centrifugal force is zero.
B) The electrostatic attraction provides the centripetal force.
C) The potential energy is at a minimum.
D) The angular momentum is always constant.
E) The electron does not radiate energy.

77). Bohr's quantization condition for angular momentum is ($\hbar = \dfrac{h}{2\pi}$) :
A) $mvr = nh$
B) $mvr = n\dfrac{h}{2\pi}$
C) $mv^2r = nh$
D) $\dfrac{mv}{r} = n\hbar$
E) $mvr^2 = n\hbar$

78). The expression for the radius of the n-th Bohr orbit for a hydrogen-like ion of nuclear charge Z is :
A) $r_n = \dfrac{\varepsilon_0 h^2 n^2}{\pi m_e e^2 Z}$
B) $r_n = \dfrac{\varepsilon_0 h^2 n^2}{\pi m_e e^2 Z^2}$
C) $r_n = \dfrac{\varepsilon_0 h^2 n}{\pi m_e e^2 Z}$
D) $r_n = \dfrac{\varepsilon_0 h^2 n^2}{4\pi m_e e^2 Z}$
E) $r_n = \dfrac{n^2}{Z} a_0$ where a_0 is the Bohr radius.

79). The total energy E_n of an electron in a hydrogen-like ion of charge Z is :
A) $E_n = -\dfrac{m_e e^4 Z^2}{8\varepsilon_0^2 h^2 n^2}$
B) $E_n = -\dfrac{m_e e^4 Z}{8\varepsilon_0^2 h^2 n^2}$
C) $E_n = -\dfrac{m_e e^4}{8\varepsilon_0^2 h^2 n^2}$
D) $E_n = \dfrac{13.6 Z^2}{n^2}$ eV
E) Both A and D are correct.

80). The physical reason why the total energy is negative is that :
A) The electron's kinetic energy is greater than its potential energy.
B) The electron is free to move.
C) The electron is bound to the nucleus, and the binding energy is defined as negative.
D) The electrostatic potential energy is positive.
E) It is an arbitrary convention.

81). For the $n = 4 \to n = 2$ transition in a hydrogen atom, the wavelength of the emitted photon is approximately :
A) 121.6 nm
B) 364.7 nm
C) 486.1 nm
D) 656.3 nm
E) 102.6 nm

82). The radiation from the previous question lies in which region of the electromagnetic spectrum ?
A) X-rays
B) Ultraviolet
C) Visible (blue-green)
D) Infrared
E) Microwave

83). The energy (in eV) of the $n = 4 \to n = 2$ transition for hydrogen is :
A) 0.66 eV
B) 1.89 eV
C) 2.55 eV
D) 3.40 eV
E) 12.1 eV

84). A hydrogen atom in its ground state absorbs a photon of wavelength 97.3 nm. The energy of this photon is :
A) 10.2 eV
B) 12.1 eV
C) 12.75 eV
D) 13.6 eV
E) 3.4 eV

85). After this absorption, the electron is excited to which energy level ?

A) n=2
B) n=3
C) n=4
D) n=5
E) n=∞

86). As the electron returns to the ground state, it can emit photons via intermediate levels. Which of the following wavelengths could NOT be emitted ?

A) 97.3 nm
B) 121.6 nm
C) 102.6 nm
D) 656.3 nm
E) 1875 nm

87). The shortest wavelength in the Balmer series ($n = \infty \to n = 2$) for hydrogen is :

A) 121.6 nm
B) 364.6 nm
C) 410.2 nm
D) 656.3 nm
E) 820.4 nm

88). The longest wavelength in the Paschen series ($n = 4 \to n = 3$) for hydrogen is :

A) 820.4 nm
B) 1094 nm
C) 1875 nm
D) 2166 nm
E) 4050 nm

89). Comparing the photons from the Balmer series limit and the Paschen series longest wavelength :

A) They have the same energy.
B) The Balmer photon is more energetic.
C) The Paschen photon is more energetic.
D) Their energies cannot be compared.
E) The Paschen photon has a shorter wavelength.

90). For the $n = 3 \to n = 2$ transition, if the energy of the photon emitted by hydrogen (Z=1) is E_H, the energy for the He$^+$ ion (Z=2) would be :

A) E_H
B) $2E_H$
C) $4E_H$
D) $8E_H$
E) $\frac{E_H}{4}$

91). For the same $n = 3 \to n = 2$ transition, the energy of the photon emitted by the Li$_2{}^+$ ion (Z=3) is :

A) E_H
B) $3E_H$
C) $6E_H$
D) $9E_H$
E) $12E_H$

92). The general rule for a hydrogen-like ion of charge Z is that the transition energy :

A) Is independent of Z.
B) Is proportional to Z.
C) Is proportional to Z^2.
D) Is proportional to 1/Z.
E) Is proportional to 1/Z^2.

93). For the He$^+$ ion, the wavelength of the $n = \infty \to n = 2$ transition (Balmer series limit) is :

A) 121.6 nm
B) 182.0 nm
C) 364.6 nm
D) 91.2 nm
E) 22.8 nm

94). This radiation for He$^+$ lies in which region of the electromagnetic spectrum ?

A) Infrared
B) Visible
C) Ultraviolet
D) X-ray
E) Gamma ray

95). The radius of the first orbit (n=1) for the He$^+$ ion is :

A) a_0
B) $\frac{a_0}{2}$
C) $2a_0$
D) $\frac{a_0}{4}$
E) $4a_0$

96). The energy of the ground state for the Li$_2{}^+$ ion is :

A) -13.6 eV
B) -27.2 eV
C) -54.4 eV
D) -122.4 eV
E) -40.8 eV

97). In the Bohr model, which quantity varies as $1/n^3$?

A) The orbital radius
B) The electron's speed
C) The total energy
D) The revolution frequency
E) The angular momentum

98). The speed of an electron in the first Bohr orbit of a hydrogen atom is approximately :

A) $\frac{c}{137}$ (where c is the speed of light)

B) $\frac{c}{274}$
C) $\frac{c}{100}$
D) $\frac{c}{50}$
E) $\frac{2c}{137}$

99). If you double the nuclear charge Z of a hydrogen-like ion, the ionization energy from the ground state is multiplied by :
A) 2
B) 4
C) 8
D) 16
E) $\sqrt{2}$

100). Among the following transitions in a hydrogen atom, which one emits the photon with the longest wavelength ?
A) $n = 5 \rightarrow n = 1$
B) $n = 4 \rightarrow n = 2$
C) $n = 3 \rightarrow n = 2$
D) $n = 4 \rightarrow n = 3$
E) $n = 6 \rightarrow n = 5$

101). In CT scanners, X-rays are produced when high-energy electrons transition to :
A) Higher energy levels
B) Lower energy levels releasing energy
C) The same energy level
D) The nucleus
E) Free space without energy change

102). The Bohr radius for n=3 compared to n=1 is :
A) 9 times larger
B) 3 times larger
C) The same
D) 3 times smaller
E) 6 times larger

103). When calculating wavelength using the Rydberg formula, if $n_i = 3$ and $n_f = 2$, the fraction $\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$ simplifies to :
A) $\frac{5}{36}$
B) $-\frac{5}{36}$
C) $\frac{5}{12}$
D) $\frac{7}{36}$
E) $\frac{1}{6}$

104). In the exercise, hemoglobin's heme group contains which ion at its center ?
A) Fe^{2+} (ferrous ion)
B) Fe^{3+} (ferric ion)
C) Cu^{2+} (copper ion)
D) Mg^{2+} (magnesium ion)
E) Zn^{2+} (zinc ion)

105). For a photon with $\lambda = 656$ nm, the energy in Joules is approximately :
A) 3.03×10^{-19} J
B) 4.56×10^{-19} J
C) 2.18×10^{-19} J
D) 6.62×10^{-19} J
E) 1.60×10^{-19} J

106). The color observed at 656 nm ($n = 3 \rightarrow n = 2$ transition) is :
A) Red
B) Blue
C) Green
D) Violet
E) Yellow

107). Converting 3.03×10^{-19} J to electronvolts gives approximately :
A) 1.89 eV
B) 2.55 eV
C) 3.40 eV
D) 0.85 eV
E) 4.86 eV

108). In arterial blood, the electron in hemoglobin's heme is in :
A) Ground state ($n = 1$)
B) First excited state ($n = 2$)
C) Second excited state ($n = 3$)
D) Ionized state
E) Continuum

109). The transition $n = 4 \rightarrow n = 2$ produces light that is :
A) Blue-green (486 nm)
B) Red (656 nm)
C) Violet (434 nm)
D) Infrared ($>$ 800 nm)
E) Ultraviolet ($<$ 400 nm)

110). For the energy formula $E_n = -\frac{13.6}{n^2}$ eV, when $n \rightarrow \infty$:
A) E approaches 0
B) E approaches -13.6 eV
C) E approaches $+13.6$ eV
D) E approaches infinity
E) E becomes undefined

111). Using $E = \frac{hc}{\lambda}$ with $\lambda = 430$ nm, the calculation sequence is :
A) $\frac{6.626 \times 10^{-34} \times 3 \times 10^8}{430 \times 10^{-9}}$
B) $\frac{430 \times 10^{-9}}{6.626 \times 10^{-34} \times 3 \times 10^8}$
C) $(6.626 \times 10^{-34}) \times (430 \times 10^{-9})$

D) $\dfrac{3 \times 10^8}{430 \times 10^{-9}}$
E) $430 \times 6.626 \times 10^{-34}$

112). The energy difference between $n = 2$ and $n = 1$ is :
A) 10.2 eV
B) 13.6 eV
C) 3.4 eV
D) 1.89 eV
E) 12.1 eV

113). For $\lambda = 430$ nm photon (≈ 2.89 eV), which transition from $n = 1$ is possible ?
A) $n = 1 \to n = 2$ (requires 10.2 eV)
B) $n = 1 \to n = 3$ (requires 12.1 eV)
C) $n = 1 \to n = 4$ (requires 12.75 eV)
D) Ionization (requires 13.6 eV)
E) None of these match

114). Deoxygenated blood appears bluish-violet because it :
A) Absorbs blue-violet light around 430 nm
B) Emits blue-violet light
C) Reflects only blue light
D) Contains no iron
E) Has higher temperature

115). The term $\dfrac{1}{\lambda}$ in the Rydberg formula has units of :
A) m^{-1} (per meter)
B) m (meters)
C) J (joules)
D) Hz (hertz)
E) Dimensionless

116). For $n = 3 \to n = 2$, calculating $\dfrac{1}{\lambda} = 1.097 \times 10^7 \times \dfrac{5}{36}$ gives :
A) 1.524×10^6 m^{-1}
B) 1.524×10^7 m^{-1}
C) 5.485×10^6 m^{-1}
D) 3.048×10^6 m^{-1}
E) 6.562×10^5 m^{-1}

117). Converting 1.524×10^6 m^{-1} to wavelength gives :
A) 656 nm
B) 486 nm
C) 434 nm
D) 410 nm
E) 397 nm

118). In radiotherapy, understanding Bohr transitions helps explain :
A) How radiation damages cancer cells through ionization
B) Only magnetic resonance
C) Only ultrasound propagation
D) Chemical reactions exclusively
E) Gravitational effects

119). For the transition $n = 4 \to n = 2$, the term $\left(\dfrac{1}{4} - \dfrac{1}{16}\right)$ equals :
A) $\dfrac{3}{16}$
B) $\dfrac{5}{16}$
C) $\dfrac{1}{4}$
D) $\dfrac{1}{16}$
E) $\dfrac{7}{16}$

120). The energy $E_3 = -\dfrac{13.6}{9}$ eV equals :
A) -1.51 eV
B) -3.40 eV
C) -4.53 eV
D) -6.80 eV
E) -0.85 eV

121). The Balmer series is important in astronomy because :
A) It produces visible light we can observe from stars
B) It only produces infrared
C) It doesn't occur in stars
D) It requires very low temperatures
E) It only occurs in laboratories

122). In MRI (Magnetic Resonance Imaging), the principle involves :
A) Nuclear spin transitions, not electronic transitions
B) Only Bohr electronic transitions
C) No quantum effects
D) X-ray absorption
E) Ultrasound waves

123). For $E = \dfrac{hc}{\lambda}$ with $\lambda = 486$ nm, the photon energy is approximately :
A) 2.55 eV
B) 1.89 eV
C) 3.40 eV
D) 4.09 eV
E) 0.85 eV

124). Comparing transitions $n = 4 \to n = 2$ (2.55 eV) and $n = 3 \to n = 2$ (1.89 eV) :
A) $n = 4 \to n = 2$ is more energetic
B) $n = 3 \to n = 2$ is more energetic
C) Both have equal energy
D) Cannot be compared
E) Both are non-radiative

125). The wavelength 430 nm corresponds to which color in the spectrum ?

A) Blue-violet
B) Red
C) Green
D) Orange
E) Infrared

126). When n increases, the energy levels :
A) Get closer together
B) Get farther apart
C) Remain equally spaced
D) Disappear
E) Become positive

127). The Lyman series produces photons in the :
A) Ultraviolet region
B) Visible region
C) Infrared region
D) Microwave region
E) X-ray region

128). For oxygen transport, hemoglobin changes color because :
A) Oxygenation changes electronic energy levels
B) Temperature increases
C) Pressure changes
D) It gains mass
E) It loses iron

129). In the simplified model, $E_1 = -13.6$ eV represents :
A) The ground state energy
B) The ionization threshold
C) The excited state
D) Zero energy
E) The photon energy

130). The energy required to ionize hydrogen from $n = 2$ is :
A) 3.40 eV
B) 13.6 eV
C) 10.2 eV
D) 1.51 eV
E) 27.2 eV

131). For $n = 5 \to n = 2$, the wavelength would be :
A) Shorter than $n = 3 \to n = 2$ (higher energy)
B) Longer than $n = 3 \to n = 2$ (lower energy)
C) Exactly the same
D) Not in the Balmer series
E) Impossible transition

132). The relationship $E \propto \frac{1}{n^2}$ means that :
A) Energy levels converge as n increases
B) Energy levels diverge as n increases
C) All levels are equally spaced
D) Energy is independent of n
E) Energy increases with n

133). In CT scanners, X-ray photons have energies typically :
A) Much higher than visible light photons
B) Much lower than visible light photons
C) Equal to visible light photons
D) Equal to radio waves
E) Zero

134). The emission spectrum of hydrogen consists of :
A) Discrete lines at specific wavelengths
B) A continuous spectrum
C) Only one wavelength
D) Random wavelengths
E) No radiation

135). For the simplified Fe^{2+} model, absorption of 430 nm light causes :
A) Excitation from $n = 1$ to an excited state
B) Ionization
C) No change
D) Emission of light
E) Nuclear decay

136). The Brackett series ($n_f = 4$) produces radiation in the :
A) Infrared region
B) Visible region
C) Ultraviolet region
D) X-ray region
E) Gamma-ray region

137). When $E = 2.89$ eV and we need to find n for transition from $n = 1$:
A) Calculate $\Delta E = E_{\text{final}} - E_{\text{initial}}$
B) Use $E = -\frac{13.6}{n^2}$
C) Compare with level energies
D) Use Rydberg formula
E) All of the above methods work

138). Oxygenated blood appears red because :
A) It doesn't absorb visible wavelengths significantly
B) It absorbs all red light
C) It emits red light
D) It contains more iron than deoxygenated blood
E) Temperature is higher

139). The Pfund series corresponds to transitions to :
A) $n = 5$
B) $n = 1$
C) $n = 2$
D) $n = 3$
E) $n = 4$

140). In the Bohr model, stationary orbits mean :
A) Electrons don't radiate energy while on these orbits
B) Electrons are stationary (not moving)

C) Orbits cannot change
D) No angular momentum
E) Zero velocity

141). The limitation of using Bohr model for hemoglobin is :
A) It's oversimplified ; real Fe^{2+} has complex electronic structure
B) It perfectly describes all properties
C) Iron cannot absorb light
D) Hemoglobin has no electrons
E) The model is exact for all atoms

142). For wavelength conversion, 1 nm equals :
A) 10^{-9} m
B) 10^{-6} m
C) 10^{-3} m
D) 10^{-12} m
E) 10^{-15} m

143). The visible range 400-800 nm corresponds to energies approximately :
A) 1.5-3.1 eV
B) 0.1-0.5 eV
C) 5-10 eV
D) 10-20 eV
E) 0.01-0.1 eV

144). In veins under skin, blood appears bluish because :
A) Light scattering and absorption of blue-violet wavelengths
B) Blood is actually blue
C) No oxygen present
D) Temperature difference
E) Magnetic effects

145). The Rydberg constant $R_H = 1.097 \times 10^7$ m^{-1} relates to :
A) The inverse wavelength of spectral lines
B) Direct wavelength measurement
C) Photon mass
D) Nuclear charge
E) Electron mass only

146). For hydrogen, the series limit occurs when :
A) $n_{\text{initial}} \to \infty$
B) $n_{\text{initial}} = 1$
C) $n_{\text{final}} = \infty$
D) $n_{\text{initial}} = n_{\text{final}}$
E) No transitions occur

147). Photon momentum $p = \dfrac{h}{\lambda}$ means :
A) Light has particle properties
B) Light has no momentum
C) Only matter has momentum
D) Momentum is independent of wavelength
E) Photons have mass

148). The medical relevance of atomic spectroscopy includes :
A) Identifying elements in tissue samples
B) Only measuring temperature
C) Only measuring pressure
D) No medical applications
E) Only theoretical interest

149). For $n = 6 \to n = 2$, the spectral line belongs to :
A) Balmer series (visible/near-UV)
B) Lyman series (UV)
C) Paschen series (IR)
D) Brackett series (IR)
E) Pfund series (far-IR)

150). The energy absorbed by Fe^{2+} electron (430 nm $\approx$ 2.89 eV) suggests transition to :
A) A higher energy level from ground state
B) A lower energy level
C) The same level
D) Complete ionization
E) Nuclear excitation