Atoms

Q.No	Question	Marks
Multiple Choice Question		
Q.154	Two statements are given below. One is labelled Assertion (A) and the other is labelled Reason (R). Read the statements carefully and choose the option that correctly describes statements A and R. Assertion (A): The mass of a nucleus is less than the mass of the constituent particles. Reason (R): Energy is absorbed when the nucleons are bound together to form the nucleus. A. Both assertion and reason are true and reason is the correct explanation for assertion. B. Both assertion and reason are true but reason is not the correct explanation of assertion. C. Assertion is true but reason is false. D. Both assertion and reason are false.	1
Q.155	The angular momentum of a hydrogen atom in the excited state is $8.28/\pi \times 10^{-15}$ eVs. What should be the minimum energy of light which can excite the electron from the ground state to this excited state? ($h = 4.14 \times 10^{-15}$ eVs) A. 0.85 eV B. 12.75 eV C. 13.6 eV D. 14.45 eV	1
Q.156	The potential energy of an electron in an excited state of the hydrogen atom is about –3 eV. How many emission spectral lines are possible for this excited electron? A. 1 B. 2 C. 3 D. 6	1

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Q.157	The ionization energy of the hydrogen atom is 13.6 eV. For a hydrogen-like atom, the transition from n = 2 to n = 1 has 81.6 eV more energy than that of hydrogen's same transition. What is the ionization energy of this hydrogen-like atom? A. 13.6 eV B. 40.8 eV C. 105.4 eV D. 122.4 eV	1
Q.158	In a hydrogen atom, the electron makes a transition from n_1 to n_2 state. Considering classical electromagnetic theory, the initial frequency of light emitted by the electron in n_1 state is 8 times as that in state n_2. What are the possible values of n_1 and n_2? A. $n_1 = 1, n_2 = 2$ B. $n_1 = 2, n_2 = 1$ C. $n_1 = 8, n_2 = 1$ D. $n_1 = 1, n_2 = 8$	1
Q.159	A hydrogen atom is in its third excited state. It de-excites by releasing a photon of the longest wavelength. What is the ratio of the velocity of the electron in the third excited state to the new state? A. 4/3 B. 3/4 C. 4/1 D. 1/4	1
Q.160	The second line of the Balmer series has a blue-green colour. Which of the given transitions may lead to violet colour? (n is principal quantum number) A. n = 3 to n = 2 B. n = 4 to n = 2 C. n = 5 to n = 2 D. n = 6 to n = 1	1
Free Response Questions/Subjective Questions		
Q.161	After a head-on inelastic collision between two hydrogen atoms that were initially in the ground states, the two atoms combine and move together into the excited state.	3

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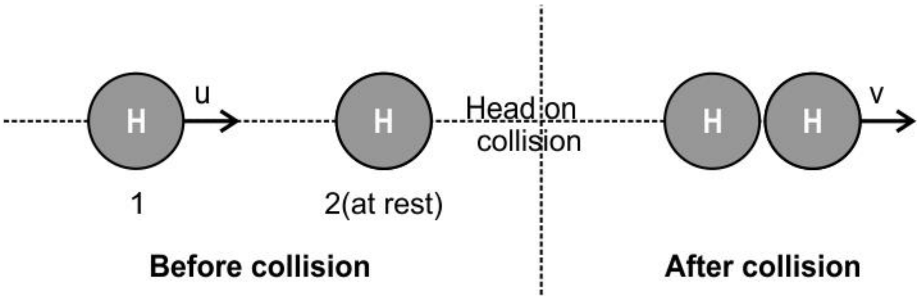
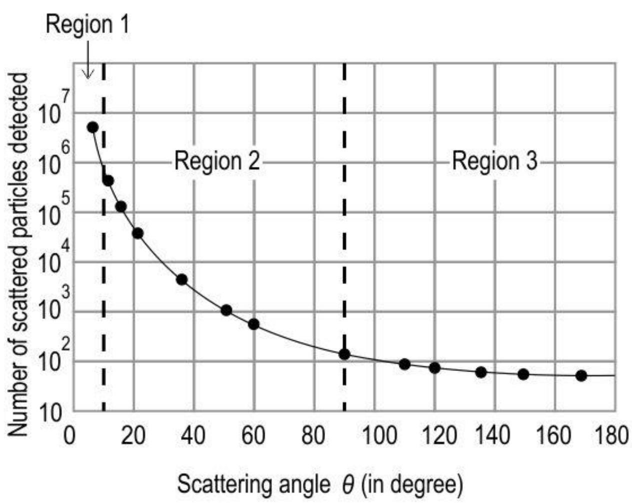
	 Determine the minimum velocity of the first H atom that can result in the minimum possible excitation in the second H-atom in this collision. Assume that in perfectly inelastic collisions between the atoms, the excess KE is used for the excitation. Use: 1 eV = 1.6×10^{-19} J and Mass of H-atom = 1.6×10^{-27} kg	
Q.162	In a Geiger Marsden experiment, an alpha particle of energy ½ mv^2 bombards the heavy target nucleus of charge Ze. In the modified version of the Geiger Marsden experiment, a bombarding particle of 3 times the mass and 2 times the charge of the alpha particle moving with the same speed as earlier, is used as the bombarding particle, keeping the heavy target nucleus the same as earlier. If the distance of closest approach in the first case is r_0, then determine by what factor does the distance of closest approach changes in the modified version of the experiment.	2
Q.163	Angular momentum of an electron in a hydrogen atom is $3h/2\pi$, here h is the plank constant. Find the wavelength of the emitted photon in terms of R (Rydberg constant) when the atom de-excites to emit visible radiations.	2
Q.164	The below graph represents the variation in the number of alpha particles scattered and the scattering angle in Rutherford's alpha particle scattering experiment. The graph is divided into three regions (separated by two dashed lines). What can be concluded about the structure of atoms from the behavior of particles observed in Region 1 and Region 3? 	2

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<table>
<tr><td>Q.165</td><td>An electron excites from first orbit to the second orbit of a hydrogen atom. By what factor will the magnetic dipole moment of the revolving electron change? Show calculations.</td><td>3</td></tr>
<tr><td>Q.166</td><td>The table below represents the energies corresponding to a few allowed energy levels of a doubly ionized hydrogen-like atom with Z=3.

<table>
<tr><th>Energy level</th><th>Energy</th></tr>
<tr><td>n=1</td><td>-122.4 eV</td></tr>
<tr><td>n=2</td><td>-30.6 eV</td></tr>
<tr><td>n=3</td><td>-13.6 eV</td></tr>
<tr><td>n=4</td><td>-7.65 eV</td></tr>
<tr><td>n=5</td><td>-4.9 eV</td></tr>
<tr><td>n=∞</td><td>0 eV</td></tr>
</table>

(a) What is the ionisation energy of the hydrogen-like atom? The transition of electron between which two energy levels corresponds to ionisation energy?

(b) What will be the energy of the photon absorbed when the electron in the n = 2 state jumps to the n = 4 state?

(c) The energy of the electron in the excited state of this hydrogen-like atom drops from – 13.6 eV to -122.4 eV. Specify the different ways in which this transition can occur.</td><td>3</td></tr>
<tr><td>Q.167</td><td>An atom can be attain three possible excited states such that,

- energy of excited atom in the 3rd state is 2 times the energy in ground state

- energy of excited atom in the 2nd excited state is 5/4 times the energy in ground state

Radiation of wavelength λ_1 is emitted during the transition from 2nd excited state to the ground state.

Radiation of wavelength λ_2 is emitted during the transition from 3rd excited state to the 2nd excited state.

Show that wavelength λ_1 is thrice the wavelength λ_2.</td><td>3</td></tr>
<tr><td>Q.168</td><td>In a Bohr model of an atom, upon de-excitation of the electron, the wavelength of radiation emitted is given as:</td><td>2</td></tr>
</table>

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	$$\lambda = \frac{n^2}{R\left[\frac{n^2}{9} - 1\right]}$$ Here R is Rydberg constant and n represents the unknown energy level from which the electron falls to the energy level n = 3. a. State the condition at which radiation of maximum wavelength is emitted. Determine this maximum wavelength. b. State the condition at which radiation of minimum wavelength is emitted. Determine this minimum wavelength.	
Q.169	a. State true or false: For every spectral line of Balmer series, an additional photon of wavelength corresponding to a Lyman spectral line is released so that the H atom reaches its ground state. b. Identify the quantum numbers across which the transition of the excited electron results in the emission of the maximum wavelength of Lyman spectral series of (a). c. Determine this maximum wavelength of the photon emitted in (b). [Use $$\frac{1}{\lambda} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$ where λ is wavelength of th radiation emitted due to transition from n_2 to n_1 level and Rydberg constant R ~ 1 x 10^7 m^{-1}]	2
Q.170	An excited Hydrogen atom is in a state n = 5. It de-excites through two consecutive transitions to reach the ground state. A photon of energy 0.967 eV is released during the first transition. a. Determine the quantum number of the in-between energy level of the atom after the first transition. b. Determine the energy of the photon released during the second transition.	3
Q.171	The emission spectra of a certain gas X indicates only three spectral lines of wavelengths 36 nm, 72 nm and 100 nm. Assuming that the energy of the highest energy level is zero, determine, a. the energy level of the ground state. b. the energy level of the first excited state.	3

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	[Consider that as in case of H atom, the difference between successive energy levels in the gas X atoms also keeps decreasing as the energy increases. Take value of hc = 1240 eV-nm]	
Q.172	When a gas is heated, the thermal energy is absorbed for the purpose of either the excitation or ionization of the gas atoms. The average kinetic energy of Hydrogen gas molecules at absolute temperature T is given as 3kT/2, where k is Boltzmann constant of value 8.6 x 10^{-5} eV/K. Using the above information, find out if the hydrogen atoms get ionized or stay in the excited state at a temperature of 10^5 K.	2
Q.173	Two spectral lines of minimum and maximum energy transitions, constituting the Balmer series, fall on two metals X and Y of work functions as given below. Which of these metals will exhibit photoelectric emission? a. Metal X with work function 1.7 eV. b. Metal Y with work function 3.1 eV.	3

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Answer key and Marking Scheme

Q.No	Answers	Marks
Q.154	C. Assertion is true but reason is false.	1
Q.155	B. 12.75 eV	1
Q.156	C. 3	1
Q.157	D. 122.4 eV	1
Q.158	A. $n_1 = 1$, $n_2 = 2$	1
Q.159	B. 3/4	1
Q.160	C. n = 5 to n = 2	1
Q.161	Minimum excitation energy required by second H atom for excitation from n = 1 to n = 2 state, with energy levels as E_1 = -13.6 eV E_2 = -3.4 eV So minimum excitation energy required = -3.4 – (-13.6) = 10.2 eV (1 mark for the correct excitation energy required) During inelastic collision, Mu = 2Mv, where v is velocity of the two atoms moving together after the collision v = u/2 Loss in KE during the collision = minimum excitation energy required by the second H-atom So, $\frac{1}{2}Mu^2 - \frac{1}{2}(2M)v^2 = \frac{1}{4}Mu^2 = 10.2eV$ (1 mark for the correct condition of energy exchange during the collision) Hence, $\frac{1}{4}Mu^2 = 10.2eV = 10.2 \times 1.6 \times 10^{-19}J$	3

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	$u^2 = \frac{4\times10.2\times1.6\times10^{-19}}{1.6\times10^{-27}}$ Solving for u = 6.3 x 10^4 m/s (1 mark for the correct final result)	
Q.162	In the first case: $\frac{1}{2}mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{Ze.2e}{r_0}$ $r_0 \propto \frac{2e}{m}$ [1 mark for identifying the correct dependence of distance of closest approach on the mass and charge of the bombarding particle] In the modified version, $r \propto \frac{2.2e}{3.m}$ So, $\frac{r}{r_0} = \frac{4e}{3m}\cdot\frac{m}{2e} = \frac{2}{3}$ Therefore, $r = \frac{2}{3}r_0$ The distance of closest approach becomes 0.66 times the earlier value of r_o. [1 mark for the correct final result]	2
Q.163	Comparing 3h/2π with nh/2π, the initial state of the hydrogen atom is $n_1 = 3$ As visible radiations are emitted the electron would de-excite to $n_2 = 2$ (Balmer series) Using, $\frac{1}{\lambda} = R(\frac{1}{2^2} - \frac{1}{n^2})$ We have $\frac{1}{\lambda} = R(\frac{1}{2^2} - \frac{1}{3^2}) = \frac{5R}{36}$ Hence, $\lambda = \frac{36}{5R}$	2

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	[0.5 marks for identifying the excited state $n_1 = 3$ and 0.5 marks for identifying $n_2 = 2$] [1 mark for finding correct wavelength]	
Q.164	Region 1: This region shows that the majority of the alpha particles passed without deflecting or deflecting by a small angle. This indicates that most of the space in an atom is empty. Region 3: This region shows that only a small portion of alpha particles have a large deflection angle ($>90^0$). This indicates that all the positive charge and mass of an atom are concentrated in a very small volume within the atom.	2
Q.165	Magnetic dipole moment is given by = M = IA Current = I = Charge/Time period = = $e \times v/2\pi r$ Area = A = πr^2 (r = radius of orbit, v = speed of electron in that orbit) Thus, $M = e \times v/2\pi r \times \pi r^2 = evr/2$ [1 mark for finding or writing correct expression of M in terms of v and r] $M = evr/2$ We know $mvr = nh/2\pi$ Therefore, $M = enh/4\pi m$ i.e. $M \propto n$ So, when the electron excites to the second orbit the magnetic dipole moment becomes 2 times that in the first orbit. [1 mark for finding correct dependence of M on n] [1 mark for correct answer]	3
Q.166	(a) The ionisation energy of this hydrogen-like atom is 122.4 eV. (0.5 marks) Ionisation energy corresponds to the transition of the electron from the ground state to $n = \infty$. (0.5 marks) (b) The energy of the photon absorbed = - 7.65 - (- 30.6) = 22.95 eV (c) -1.5 eV and -13.6 eV corresponds to n=3 and n=1 state.	3

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	There are two possible ways in which the electron can jump from n=3 to n=1 states 1. n=3 to n=1 (0.5 marks) 2. n=3 to n=2 to n=1 (0.5 marks)	
Q.167	For the transition 2nd excited state to the ground state of the atom: $\frac{5E}{4} - E = \frac{hc}{\lambda_1}$ $\frac{E}{4} = \frac{hc}{\lambda_1}$ $\lambda_1 = \frac{4hc}{E}$ ....(1) [1 mark for the correct relation between energy and wavelength of radiation emitted] For the transition 3rd excited state to the 2nd excited state of the atom, $2E - \frac{5E}{4} = \frac{hc}{\lambda_2}$ $\frac{3E}{4} = \frac{hc}{\lambda_2}$ $\lambda_2 = \frac{4hc}{3E}$ ....(2) [1 mark for the correct relation between energy and wavelength of radiation emitted] Ratio $\lambda_1 : \lambda_2 = 3 : 1$ [1 mark for the correct final relation]	3
Q.168	a. Simplifying the given equation: $\frac{1}{\lambda} = \frac{R}{n^2}\left[\frac{n^2}{9} - 1\right] = R\left[\frac{1}{3^2} - \frac{1}{n^2}\right]$ For maximum wavelength (least energetic photon) to be emitted, $n_f = 3$, $n_i = 4$	2

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	$$\frac{1}{\lambda_{max}} = R\left[\frac{1}{3^2} - \frac{1}{4^2}\right] = \frac{7R}{144}$$ $$\lambda_{max} = \frac{144}{7R}$$ [0.5 mark for the correct condition] [0.5 mark for the correct final wavelength] b. For minimum wavelength (most energetic photon) to be emitted, $n_f = 3$, n_i = infinity So $$\frac{1}{\lambda_{min}} = R\left[\frac{1}{3^2} - \frac{1}{\infty}\right] = \frac{R}{9}$$ $$\lambda_{min} = 9/R$$ [0.5 mark for the correct condition] [0.5 mark for the correct final wavelength]	
Q.169	a. True. [0.5 mark for correct answer] b. For maximum wavelength Lyman series, the transition is between $n_f = 1$ and $n_i = 2$. [0.5 mark for the correct values of n_f and n_i] c. Using $$\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{2^2}\right] = 1 \times 10^7 \times \frac{3}{4}$$ $\lambda = 1.33 \times 10^{-7} = 133 \times 10^{-9}$ m = 133 nm	2
Q.170	a. The initial excited energy level of H atom: $E_5 = -13.6/n^2 = -13.6/52 = -0.544$ eV Energy of photon released during the first transition = 0.967 eV	3

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	Energy level of the in-between level occupied by the atom after the first transition = -0.544 – 0.967 = -1.511 eV [1 mark for the correct value of energy of the intermediate level] Quantum number of in-between level occupied by the atom after the first transition, $E_n = -1.511 = -13.6/n^2$ $n^2 = -13.6/-1.511$ n = 3 [1 mark for the correct value of n] b. Energy of the photon released during the second transition: -1.511 – (-13.6) = 12.089 eV [1 mark for the correct value of the energy of photon released]	
Q.171	a. Only three emission spectral lines imply only three possible energy states, that is, ground, first and second, i.e., n = 1,2,3 respectively. [0.5 mark for recognising the 3 possible states] Given that $E_3 = 0$ λ_{min} = 36 nm is emitted for transition from n = 3 to n = 1 (ground state) [0.5 mark for identifying the correct quantum numbers for λ_{min}] So $E_1 = \frac{hc}{\lambda_{min}} = \frac{1240}{36}$ = 34.44 eV (energy level of the ground state) [1 mark for the correct value of energy level of the ground state] b. λ_{max} = 100 nm is emitted for transition between n = 3 (second excited state) to n = 2 (first excited state) [0.5 mark for identifying the correct quantum numbers for λ_{max}] So	3

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	$E_2 = \frac{hc}{\lambda_{max}} = \frac{1240}{100}$ = 12.4 eV (energy level of the first excited state) [0.5 mark for the correct value of energy level of the ground state]	
Q.172	Total thermal energy absorbed by the H atom at 10^5 K = 3kT/2 $= \frac{3 \times 8.6 \times 10^{-5} \times 10^{5}}{2} = 12.9$ eV [1 mark for the correct calculation of energy value] As the ionization energy of H atom being 13.6 eV > Absorbed thermal energy of 12.9 eV, the H atom will be in the excited state. They fail to get ionized. [1 mark for the correct conclusion]	2
Q.173	Energy of photon emitted can be calculated by the formula $E = 13.6\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$ The first Balmer spectral line (of minimum energy) emission could be due to the transition between $n_1 = 2$ and $n_2 = 3$ The energy of this photon $= 13.6\left[\frac{1}{2^2} - \frac{1}{3^2}\right] = 1.9\ eV$ [1 mark for the correct calculation of energy of photon] As the energy of an incident photon is greater than the work function of metal X but less than the work function of metal Y, this photon can result in photoelectric emission in only metal X. [0.5 mark for the correct conclusion on the metal] The second Balmer spectral line (of maximum energy) emission corresponds to the transition: $n_1 = 2$ and n_2 = infinity The energy of this photon	3

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	$= 13.6 \left[\frac{1}{2^2} - \frac{1}{\infty^2}\right] = 3.4\ eV$ [1 mark for the correct calculation of energy of photon] As the energy of the incident photon exceeds the work functions of both the metal X & Y, this photon can result in photoelectric emission in both metals X and Y. [0.5 mark for the correct conclusion on the metal]	

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