D PHYSICS

CSIR-NET, GATE, SET, JEST, IIT-JAM, BARC, TIFR

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PHYSICAL SCIENCE

ATOMIC MOLECULAR PHYSICS

Previous Year Questions [Topic-Wise]

With Answer Key

CSIR-NET/JRF I GATE I JEST I TIFR

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❖ Bohr's Atomic Model

▪ CSIR-NET PYQ

1. Given that the ground state energy of the hydrogen atom is -13.6eV, then the ground state energy of positionium (which is a bound state of an electron and a positron) is **[NET Dec. 2011]**

(a) 6.8eV (b) -6.8eV
(c) -13.6eV (d)13.6eV

2. A muon $(\mu^-)$from cosmic rays is trapped by a proton to form a hydrogen-like atom. Given that a muon approximately 200 times heavier than an electron, the longest wavelength of the spectral line (in the analogy of the Lyman series) of such an atom will be **[NET June 2013]**

(a) 5.62 A^0 (b) 6.67 A^0
(c) 3.75 A^0 (d) 13.3 A^0

3. A photon of energy 115.62 keV ionizes a K-shell electron of a Be atom. One L-shell electron jumps to the K-shell to fill this vacancy and emits a photon of energy 109.2 keV in the process. If the ionization potential for the L-shell is 6.4 keV , the kinetic energy of the ionized electron is **[NET June 2018]**

(a) 6.42 keV (b) 12.82 keV
(c) 20 eV (d) 32 eV

4. A bound electron and hole pair interacting via Coulomb interaction in a semiconductor is called an exciton. The effective masses of an electron and a hole are about $0.1m_e$ and $0.5m_e$ respectively, where m_e is the rest mass of the electron. The dielectric constant of the semiconductor is 10 . Assuming that the energy levels of the excitons are hydrogen- like, the binding energy of an exciton (in units of the Rydberg constant) is closest to **[NET June 2019]**

(a) 2×10^{-3} (b) 2×10^{-4}
(c) 8×10^{-4} (d) 3×10^{-3}

5. A negative muon, which has a mass nearly 200 times that of an electron, replaces an electron in a Li atom. The lowest ionization energy for the muonic Li atom is approximately **[NET Dec. 2019]**

(a) the same as that of He
(b) the same as that of normal Li
(c) 200 times larger than that of normal Li
(d) the same as that of normal Be

6. The wavelength of the first Balmer line of hydrogen is 656 nm. The wavelength of the corresponding line for a hydrogenic atom with $Z = 6$ and nuclear mass of 19.92×10^{-27} kg is **[NET Nov. 2020]**

(a) 18.2 nm (b) 109.3 nm
(c) 143.5 nm (d) 393.6 nm

7. In the absorption spectrum of H-atom, the frequency of transition from the ground state to the first excited state is v_H. The corresponding frequency for a bound state of a positively charged muon (μ^*) and an electron is v_μ. Using $m_\mu = 10^{-28}$ kg, $m_e = 10^{-30}$ kg and $m_p \gg m_e, m_\mu$, the value of $(v_\mu - v_H)/v_H$ is **[NET June 2022]**

(a) 0.001 (b) -0.001 (c) -0.01 (d) 0.01

8. The ionization potential of hydrogen atom is 13.6 eV, and λ_H and λ_D denote longest wavelengths in Balmer spectrum of hydrogen

and deuterium atoms, respectively. Ignoring the fine and hyperfine structures, the percentage difference $y = \frac{\lambda_H - \lambda_D}{\lambda_H} \times 100$, is closest to

[NET Dec 2023]

(a)1.0003% (b)−0.03%
(c)0.03% (d)−1.0003%

▪ GATE PYQ

1. If R_1 is the value of the Rydeberg constant assuming the mass of the nucleus to be infinitely large compared that of an electron and R_2 is the value of the Rydeberg constant taking the nuclear mass to be 7500 times th mass of the electron, then the ratio $\frac{R_2}{R_1}$ is **[GATE 2002]**

(a) a little less than unity
(c) infinitely small
(b) a little more than unity
(d) infinitely large

2. If the wavelength of the first line of the Balmer series in the hydrogen spectrum is λ, then the wavelength of the first line of the Lyman series is first line of the Lyman series is **[GATE 2002]**

(a) $\frac{27}{5}\lambda$ (b) $\frac{5}{27}\lambda$ (c) $\frac{32}{27}\lambda$ (d) $\frac{27}{32}\lambda$

3. The electronic ground state energy of the Hydrogen atom is -13.6eV. The highest possible electronic energy eigenstate has an energy equal to **[GATE 2017]**

(a) 0 (b) 1Ev (c) +13.6Ev (d) ∞

4. Positronium is an atom made of an electron and a positron. Given the Bohr radius for the ground state of the Hydrogen atom to be 0.53 Angstroms, the Bohr radius for the ground state of positronium is ……. Angstroms. (up to two decimal places). **[GATE 2017]**

5. Consider a gas of hydrogen atoms in the atmosphere of the Sun where the temperature is 5800 K. If a sample from this atmosphere contains 6.023×10^{23} number of hydrogen atoms in the ground state, the number of hydrogen atoms in the first excited state is approximately 8×10^{n}, where n is an integer. The value of n is

…..(Boltzmann constant: 8.617×10^{-5}eV/K) **[GATE 2020]**

6. Which one of the following is a dimensionless constant?
(A) Permittivity of free space
(B) Permeability of free space
(C) Bohr magneton
(D) Fine structure constant **[GATE 2023]**

▪ JEST PYQ

1. Consider the Bohr model of the hydrogen atom. If α is the fine structure constant, then the velocity of th electron in its lowest orbit is **[JEST 2012]**

(a) $\frac{c}{1+a}$ (b) $\frac{c}{1+\alpha^2}$ or $(1-\alpha)c$
(c) $\alpha^2 c$ (d) αc

2. The binding energy of the hydrogen atom (electron bound to proton) is 13.6eV. The binding energy of positronium (electron bound to positron) is **[JEST 2013]**

(a) 13.6/2 eV (b) 13.6/1810eV
(c) 13.6 × 1810 eV (d) 13.6 × eV

3. If a proton were ten times lighter, then the ground state energy of the electron in a hydrogen atom would be **[JEST 2013]**

(a) less (b) more
(c) same
(d) less, more or equal depending on the electron mass

4. A hydrogen atom in its ground state is collided with an electron of kinetic energy 13.377eV. The maximum factor by which the radius of the atom would increase is **[JEST 2014]**

(a) 7 (b) 8 (c) 49 (d) 64

5. If the Rydberg constant of an atom of finite nuclear mass is αR_∞, where R_∞ the Rydberg constant corresponding to an infinite nuclear mass, the ratio of the electronic to nuclear mass of the atom is:-

(a) $\frac{(1-\alpha)}{\alpha}$ (b) $\frac{(\alpha-1)}{\alpha}$ (c) $(1-\alpha)$ (d) $\frac{1}{\alpha}$

[JEST 2016]

6. What is the binding energy of an electron in the ground state of a He^{+}ion? **[JEST 2019]**

(a) 6.8ev (b) 13.6eV
(c) 27.2ev (d) 54.4ev

▪ TIFR PYQ

1. Given that the ionization energies of Hydrogen (^{1}H) and Lithium (^{3}Li) are 13.6eV and 5.39eV respec tively. The effective nuclear charge experienced by the valence electron of the ^{3}Li atom may be estimated in terms of proton charge e as **[TIFR 2011]**

(a) $3.00e$ (b) $1.59\bar{e}$
(c) 1.26e (d) $0.63e$

2. Consider the high excited states of a hydrogen atom corresponding to large values of the principal quantum number ($n \gg 1$). The wavelength λ of a photon emitted due to an electron undergoing a transition betwee two such states with consecutive values of n(i.e. $\psi_{n+1} \rightarrow \psi_n$) is related to the wavelength λ_α of the K_α line of hydrogen by **[TIFR 2012]**

(a) $\lambda = \frac{n^3}{8}\lambda_\alpha$ (b) $\lambda = \frac{3n^3}{8}\lambda_\alpha$
(c) $\lambda = n^2\lambda_\alpha$ (d) $\lambda = \frac{4}{n^2}\lambda_\alpha$

3. The velocity of an electron in the ground state of a hydrogen atom is v_H. If v_p be the velocity of an electron i the ground state of positronium, then **[TIFR 2013]**

(a) $v_p = v_H$ (b) $v_p = 2v_H$
(c) $v_p = \frac{v_H}{2}$ (d) $v_p = \sqrt{2}v_H$

4. A sample of ordinary hydrogen ($^{1}_{1}$H) gas in a discharge tube was seen to emit the usual Balmer spectrum. O careful examination, however, it was found that the H_a line in the spectrum was split into two fine lines, one a intense line at 656.28 nm and the other a faint line at 656.04 nm. From this, one can conclude that the ga Sample had a small impurity of **[TIFR 2015]**

(a) $^{3}_{1}$H (b) $^{2}_{1}$H (c) $^{4}_{2}$He (d) H_2O

5. The energy of an electron in the ground state of the He atom is -79eV. Considering the Bohr model of the atom, what would be 10 times the first ionization potential for a He^{+} ion, in units of eV? **[TIFR 2017]**

6. Hydrogen atoms in the atmosphere of a star are in thermal equilibrium, with an average kinetic energy of 1eV. The ratio of the number of hydrogen atoms in the 2 nd excited state ($n = 3$) to the number in the ground state ($n = 1$) is **[TIFR 2017]**

(a) 3.16×10^{-11} (b) 1.33×10^{-8}
(c) 3.16×10^{-8} (d)5.62×10-6

7. A sample of hydrogen gas was placed in a discharge tube and its spectrum was measured using a his resolution spectrometer: The H_α line in the spectrum was found to be split into two lines, a high intensity at 656.28 nm, and a low intensity line at 656.01 nm. This indicates that the hydrogen sample was contaminated with **[TIFR 2020]**

(a) deuterium (b) tritium
(c) helium (d) water vapor

8. A hydrogen atom in its ground state collides with an electron of energy 13.377eV, absorbs most of the energy of the electron, and goes into an excited state. The maximum possible fraction $f \equiv \frac{R_{\text{Final}} - R_{\text{Initial}}}{R_{\text{tnitial}}}$ by which its radius R would increase will be **[TIFR 2021]**

(a) $f = 0.48$ (b) $f = 0.60$
(c) $f = 0.63$ (d) $f = 0.07$

9. An atom of mass M at rest emits or absorbs a photon of frequency v and recoils with a momentum p. The frequency of the internal transition of electronic levels is v_0 without accounting for recoil. Assuming the process is nonrelativistic, the fractional difference between the photon frequency for emission and absorption $(v - v_0)/v$, respectively, are given by **[TIFR 2023]**

(a) $-\frac{2hv}{Mc^2}$ (emission), $+\frac{2hv}{Mc^2}$ (absorption)
(b) $+\frac{hv_0}{2Mc^2}$ (emission), $-\frac{hv_0}{2Mc^2}$(absorption)
(c) $-\frac{hv}{2Mc^2}$ (emission), $+\frac{hv}{2Mc^2}$ (absorption)
(d) $-\frac{2hv_0}{Mc^2}$ (emission), $+\frac{2hv_0}{Mc^2}$ (absorption)

10. The energy gap between the $n = 1$ and the $n = 2$ energy levels of a hydrogen atom is denoted E_0. Now, consider a muonic carbon ion C^{5+}, i.e., a carbon nucleus ($^{12}_{6}C$) orbited by a muon $\mu(q = -e, M_\mu = 210m_e)$. The energy of the photon emitted in the transition of the muon from the $n = 3$ level to the $n = 2$ level of this ion will be approximately. **[TIFR 2023]**

(a) $7560E_0$ (b) $235E_0$
(c) $1050E_0$ (d) $1400E_0$

ANSWER KEY

- **CSIR NET PYQ**

1. b	2. b	3. c	4. c	5. a	6. a
7. c	8. c				

- **GATE PYQ**

1. a	2. b	3. a	4. 1.06	5. 14	6. d

- **JEST PYQ**

1. d	2. a	3. a	4. c	5. a	6. d

- **TIFR PYQ**

1. c	2. b	3. a	4. a	5. 246	6. b
7. c	8. c	9. c	10. d		

Atomic Spectra (Vector atomic Model & Fine Structure)

- **CSIR-NET PYQ**

1. The ratio of intensities of the D_1 and D_2 lines of sodium at high temperature **[NET June 2011]**

(a) 1: 1 (b) 2: 3
(c) 1: 3 (d) 1: 2

2. The spin-orbit interaction in an atom is given by $H = a\vec{L}.\vec{S}$, where $\vec{L}$ and $\vec{S}$ denote the orbital and spin angular momenta respectively, of the electron. The splitting between the levels $^2P_{3/2}$ and $^2P_{1/2}$ is **[NET June 2012]**

(a) $\frac{3}{2}a\hbar^2$ (b) $\frac{1}{2}ah^2$
(c) $3a\hbar^2$ (d) $\frac{5}{2}a\hbar^2$

3. The single particle energy difference between the p-orbitals (i.e. $p_{3/2}$ and $p_{1/2}$) of the nucleus $^{114}_{50}$Sn is 3MeV. The energy difference between the states in its $1f$ orbital is **[CSIR-DEC 2012]**

(a) -7MeV (b) 7MeV
(c) 5MeV (d) -5MeV

4. How does the total angular quantum number J change in the transition of $Cr(3d^6)$ atom ionizes to $Cr^{2+}(3d^4)$? **[NET June 2014]**

(a) Increases by 2 (b) Decreases by 2
(c) Decreases by 4 (d) Does not change

5. The LS configurations of the ground state of ^{12}Mg, ^{13}Al, V^{17}Cl and ^{18}Ar are, respectively. **[NET Dec. 2015]**

(a) $^3S_1$, $^2P_{1/2}$, $^2P_{1/2}$ and $^1S_0$
(b) $^3S_1$, $^2P_{3/2}$, $^2P_{3/2}$ and $^3S_1$
(c) $^1S_0$, $^2P_{1/2}$, $^2P_{3/2}$ and $^1S_0$
(d) $^1S_0$, $^2P_{3/2}$, $^2P_{1/2}$ and $^3S_1$

6. Of the following term symbols of the np^2 atomic configurations, $^1P_0$, $^3P_0$, $^3P_1$, $^3P_2$ and $^1D_2$ which is the grounded state? **[NET June 2015]**

(a) $^3P_0$ (b) $^1P_0$ (c) $^3P_2$ (d) $^3P_1$

7. In the L-S coupling scheme, the terms arising from two non-equivalent p-electrons are **[NET Dec. 2016]**

(a) ^{3} S, ^{1}P, ^{3}P, ^{1}D, ^{3}D
(b) ^{1} S, ^{3} S, ^{1}P, ^{1}D
(c) ^{1}S, ^{3} S, ^{3}P, ^{3}D
(d) ^{1} S, ^{3} S, ^{1}P, ^{3}P, ^{1}D, ^{3}D

8. The ground state electronic configuration of ^{22}Ti is [Ar]$3d^24s^2$. Which state, in the standard spectroscopic notations, is not possible in this configuration? **[CSIR-JUNE 2016]**

(a) $^1F_3$ (b) $^1S_0$
(c) $^1D_2$ (d) $^3P_0$

9. The total spin of a hydrogen atom is due to the contribution of the spins of the electron and the proton. In the high temperature limit, the ratio of the number of atoms in the spin-1 state to the number in the spin- 0 state is **[CSIR-DEC 2016]**

(a) 2 (b) 3 (c) ½ (d) 1/3

10. The separations between the adjacent levels of a normal multiple are found to be 22 cm^{-1} and 33 cm^{-1}. Assume that the multiplet is described well by the $L-S$ coupling scheme and the Lande's interval rule, namely $E(J)-E(J-1)=AJ$, where A is a constant. The term notations for this multiple is **[NET Dec. 2017]**

(a) $^3P_{0,1,2}$ (b) $^3F_{2,3,4}$
(c) $^3G_{3,4,5}$ (d) $^3D_{1,2,3}$

11. If the fine structure splitting between the $2^2P_{3/2}$ and 2. $^2P_{1/2}$ levels in the hydrogen atom is 0.4 cm^{-1}, the corresponding splitting in Li^{2+} will approximately be **[NET Dec. 2017]**

(a) 1.2 cm^{-1} (b) 10.8 cm^{-1}
(c) 32.4 cm^{-1} (d) 36.8 cm^{-1}

12. The value of the Lande g-factor for a fine structure level defined by the quantum numbers $L = 1$ and J $= 2$ and S $= 1$, is **[CSIR-JUNE 2018]**
(a) 11/6 (b) 4/3
(c) 8/3 (d) 3/2

13. The excited state $(n = 4, l = 2)$ of an election in an atom may decay to one or more of the lower energy levels shown in the diagram below.

$n = 4$ $\overline{l = 2}$
$n = 3$ $\overline{l = 0}$ $\overline{l = 1}$ $\overline{l = 2}$
$n = 2$ $\overline{l = 1}$

Of the total emitted light, a fraction $\frac{1}{4}$ comes from the decay to the state ($n = 2, l = 1$). Based on selection rules, the fractional intensity of the emission line due to the decay to the state $(n = 3, l = 1)$ **[NET Dec. 2018]**
(a) $\frac{3}{4}$ (b) $\frac{1}{2}$ (c) $\frac{1}{4}$ (d) 0

14. A doubly charged ion in the angular momentum state $(J = 2, J_3 = 1)$ meets a gas of polarized electrons $(S_3 = 1/2)$ and gets neutralized. If the orbital angular momentum transferred in the process is zero, the probability that the neutrai atom is in the $(J = 2, J_3 = 2)$ state is **[NET June 2019]**
(a) 2/5 (b) 2/3
(c) 1/5 (d) 1/3

15. The outermost shell of an atom of an element is $3d^3$. The spectral symbol for the ground state is **[NET Dec. 2019]**
(a) $^4F_{3/2}$ (b) $^4F_{9/2}$
(c) $^4D_{7/2}$ (d) $^4D_{1/2}$

16. The |3,0,0⟩ state (in the standard notation $|n, l, m\rangle$) of the H-atom in the non-relativistic theory decays to the state |1,0,0⟩ via two dipole transitions. The transition route and the corresponding probability are **[NET June 2021]**
(a) $|3,0,0\rangle \rightarrow |2,1,-1\rangle \rightarrow |1,0,0\rangle$ and $\frac{1}{4}$
(b) $|3,0,0\rangle \rightarrow |2,1,1\rangle \rightarrow |1,0,0\rangle$ and $\frac{1}{4}$
(c) $|3,0,0\rangle \rightarrow |2,1,0\rangle \rightarrow |1,0,0\rangle$ and $\frac{1}{3}$
(d) $|3,0,0\rangle \rightarrow |2,1,0\rangle \rightarrow |1,0,0\rangle$ and $\frac{2}{3}$

17. The electronic configuration of ^{12}C is $1s^2 2s^2 2p^2$. Including LS coupling, the correct ordering of its energies is **[NET June 2022]**
(a) $E(^3P_2) < E(^3P_1) < E(^3P_0) < E(^1D_2)$
(b) $E(^3P_0) < E(^3P_1) < E(^3P_2) < E(^1D_2)$
(c) $E(^1D_2) < E(^3P_2) < E(^3P_1) < E(^3P_0)$
(d) $E(^3P_1) < E(^3P_0) < E(^3P_2) < E(^1D_2)$

- **GATE PYQ**

1. The Lande g-factor for the $^3P_1$ level of an atom is: **[GATE 2001]**
(a) ½ (b) 3/2 (c) 5/2 (d) 7/2

2. The spin-orbit coupling constant for the upper state of sodium atom which emits D lines of wave numbers 16956.2 and 16973.4 cm^{-1} is : **[GATE 2003]**
(a) 15 cm^{-1} (b) 11.4 cm^{-1}
(c) 12.5 cm^{-1} (d) 15.1 cm^{-1}

3. The spectral term for the atom with 70% subshell and only $s = 3/2$ is **[GATE 2003]**
(a) $^3P_0$ (b) $^4F_{9/2}$
(c) $^3F_{1/2}$ (d) $^4P_{1/2}$

4. Deuteron in its ground state has a total angular momentum J $= 1$ and a positive parity. The corresponding orbital angular momentum L and spin S combinations are **[GATE 2004]**
L $= 0$, S $= 1$ and L $= 2$, S $= 0$
(b) L $= 0$, S $= 1$ and L $= 1$, S $= 1$
(c) L $= 0$, S $= 1$ and L $= 2$, S $= 1$
(d) L $= 1$, S $= 1$ and L $= 2$, S $= 1$

5. The spectral terms for a certain electronic configuration are given by ^{3}D, ^{1}D, ^{3}P, ^{1}P, ^{5} S, ^{3} S. The term with the lowest energy is **[GATE 2004]**
(a) ^{5} S (b) ^{3}P (c) ^{3}D (d) ^{3} S

6. The degeneracy of the spectral term ^{3} F is:
(a) 7 (b) 9 (c) 15 (d) 21

7. The Lande g factor for the level $^3D_3$ is: **[GATE 2004]**
(a) $\frac{2}{3}$ (b) $\frac{3}{2}$ (c) $\frac{3}{4}$ (d) $\frac{4}{3}$

8. The degeneracies of the J-states arising from the ^{3}P term with spin-orbit inteaction are **[GATE 2004]**
(a) 1,3,5 (b) 1, 2,3
(c) 3,5,7 (d)2,6,10

9. For an electron in hydrogen atom, the states are characterized by the usual quantum numbers n, L, m. The electric dipole transition between any two states requires that **[GATE 2005]**
(a) $\Delta\ell = 0, \Delta m_\ell = 0, \pm 1$

(b) $\Delta\ell = \pm 1, \Delta m_\ell = \pm 1, \pm 2$
(c) $\Delta\ell = \pm 1, \Delta m_\ell = 0, \pm 1$
(d) $\Delta\ell = \pm 1, \Delta m_\ell = 0, \pm 2$

10. In a two electron atomic system having orbital and spin angular momenta ℓ_1, ℓ_2 and $s_1 s_2$ respectively, the coupling strengths are defined as $\Gamma_{\ell_1\ell_2}, \Gamma_{s_1 s_2}, \Gamma_{\ell_1 s_1}, \Gamma_{\ell_2 s_2}, \Gamma_{\ell_1 s_2}$ and $\Gamma_{\ell_2 s_1}$. For the J-J coupling scheme to be applicable, the coupling strengths MUST satisty the condition. **[GATE 2005]**

(a) $\Gamma_{\ell_1\ell_2}, \Gamma_{s_1,s_2} > \Gamma_{\ell_1 s_1}, \Gamma_{\ell_2,s_2}$
(b) $\Gamma_{\ell_1 s_1}, \Gamma_{i_2 s_2} > \Gamma_{\ell_1\ell_2}, \Gamma_{s_1 s_2}$
(c) $\Gamma_{\ell_1 s_2}, \Gamma_{\ell_2 s_1} > \Gamma_{\ell_1 C_2}, \Gamma_{s_1 s_2}$
(d) $\Gamma_{\ell_1 s_2}, \Gamma_{\ell_2 s_1} > \Gamma_{\ell_1 s_1}, \Gamma_{s_2 s_2}$

11. The allowed states for He$(2p^2)$ configuration are **[GATE 2007]**

(a) $^1S_0$, $^3S_1$, $^1P_1$, $^3P_{0,1,2}$ $^1D_2$ and $^3D_{1,2,3}$
(b) $^1S_0$, $^3P_{0,1,2}$ and $^1D_2$
(c) $'P_1$ and $^3P_{0,1,2}$
(d) $^1S_0$ and $^2P_1$

12. In accordance with the selection rules of electric dipole transitions, the 4^3P_1, state of helium can decay by photon emission to the states **[GATE 2007]**

(a) $2^1S_0, 2^1P_1$ and 3^1D_2
(b) $3^1P_1, 3^1D_2$ and 3^1S_0
(c) $3^3P_2, 3^3D_3$ and 3^3P_0
(d) $2^3S_1, 3^3D_2$ and 3^3D_1

13. If an atom is in the $^3D_3$ state, the angle between its orbital and spin angular momentum vectors $(\vec{L}$ and $\vec{S})$ is: **[GATE 2007]**

(a) $\cos^{-1}\frac{1}{\sqrt{3}}$ (b) $\cos^{-1}\frac{2}{\sqrt{3}}$
(c) $\cos^{-1}\frac{1}{2}$ (d) $\cos^{-1}\frac{\sqrt{3}}{2}$

14. The last two terms of the electronic configuration of manganese (Mn) atom is $3d^5 4s^2$. The term factor of Mn^{4+} ion is : **[GATE 2008]**

(a) $^4D_{1/2}$ (b) $^4F_{3/2}$
(c) $^3F_{92}$ (d) $^3D_{7/2}$

15. For a multi-electron atom, ℓ, L and S specify the one-electron orhital angular momentum, total orbital angular momentum and total spin angular momentum, respectively. The selection rules for electric dipole transition between the two electronic energy levels, specified by ℓ, L and S are **[GATE 2011]**

(a) $\Delta L = 0, \pm 1; \Delta S = 0; \Delta\ell = 0, \pm 1$
(b) $\Delta L = 0, \pm 1; \Delta S = 0; \Delta\ell = \pm 1$
(c) $\Delta L = 0, \pm 1: \Delta S = \pm 1; \Delta\ell = 0, \pm 1$
(d) $\Delta l = 0, \pm 1; \Delta S = \pm 1; \Delta\ell = \pm 1$

16. The terms $\{j_1, j_2\}$, arising from 2 $s^1$3 d^1 electronic configuration in j − j coupling scheme are **[GATE 2012]**

(a) $\left\{\frac{1}{2},\frac{3}{2}\right\}_{2,1}$ and $\left\{\frac{1}{2},\frac{5}{2}\right\}_{3,2}$
(b) $\left\{\frac{1}{2},\frac{1}{2}\right\}_{1,0}$ and $\left\{\frac{1}{2},\frac{3}{2}\right\}_{2,1}$
(c) $\left\{\frac{1}{2},\frac{1}{2}\right\}_{1,0}$ and $\left\{\frac{1}{2},\frac{5}{2}\right\}_{3,2}$
(d) $\left\{\frac{3}{2},\frac{1}{2}\right\}_{2,1}$ and $\left\{\frac{1}{2},\frac{5}{2}\right\}_{3,2}$

17. The number of spectroscopic terms resulting from the L.S. coupling of a $3p$ electron and a $3d$ electron is …….. **[GATE 2016]**

18. Using Hund's rule, the total angular momentum quantum number J for the electronic ground state of the nitrogen atom is **[GATE 2017]**

(a) ½ (b) 3/2 (c) 0 (d) 1

19. The term symbol for the electronic ground state of oxygen atom is **[GATE 2018]**

(a) $^1S_0$ (b) $^1D_2$ (c) $^3P_0$ (d) $^3P_2$

20. The ground state electronic configuration of the rare-earth ion (Nd^{3+}) is $[Pd]4f^3 5s^2 5p^6$. Assuming L-S coupling, the Lande g-fictor of this ion is 8/11 . The effective magnetic moment in units of Bohr magneton μ_B (rounded off to two decimal places) is…….. **[GATE 2019]**

21. A hydrogenic atom is subjected to a strong magnetic field. In the absence of spin-orbit coupling, the number of doubly degenerate states created out of the d-level is…….. **[GATE 2020]**

22. The spin-orbit effect splits the $^2P \rightarrow {}^2S$ transition (wavelength, $\lambda = 6521$ A) in Lithium into two lines with separation of $\Delta\lambda = 0.14$Å. The corresponding positive value of energy difference between the above two lines, in eV, is $m \times 10^{-5}$. The value of m (rounded off to the nearest integer) is **[GATE 2021]**
[Given: Planck's constant, $h = 4.125 \times 10^{-15}$eV-sec, Speed of light, $c = 3 \times 10^8$ msec^{-1}]

23. Among the term symbols **[GATE 2021]**
$^4S_1$, $^2D_{7/2}$, $^3S_1$ and $^2D_{5/2}$

Choose the option(s) possible in the LS coupling notation.
(a) $^2D_{7/2}$ (b) $^4S_1$
(c) $^3S_1$ (d) $^2D_{5/2}$

24. The spin $\vec{S}$ and orbital angular momentum $\vec{L}$ of an atom precess about $\vec{J}$, the total angular momentum. $\vec{J}$ precesses about an axis fixed by a magnetic field $\vec{B}_1 = 2B_0\hat{z}$, where B_0 is a constant. Now, the magnetic field is changed to $\vec{B}_2 = B_0(\hat{x} + \sqrt{2}\hat{y} + \hat{z})$. Given the orbital angular momentum quantum number $l = 2$ and spin quantum number $s = 1/2$, θ is the angle between $\vec{B}_1$ and $\vec{J}$ for the largest possible values of total angular quantum number j and its z-component j_z. The value of θ (in degree, rounded off to the nearest integer) is…….. **[GATE 2021]**

25. An excited state of Ca atom is [Mg]$3p^5 4\,s^2 3\,d^1$. The spectroscopic terms corresponding to the total orbital angular momentum are **[GATE 2022]**
(a) S, P, and D (b) P. D, and F
(c) P and D (d) S and P

26. Which one of the following is dimensionless constant? **[GATE 2023]**
(a) Permittivity of free space
(b) Permeability of free space
(c) Bohr magneton
(d) Fine structure constant

27. The atomic number of an atom is 6 . What is the spectroscopic notation of its ground state, according to Hund's rules? **[GATE 2023]**
(a) $^3P_0$ (b) $^3P_1$ (c) $^3D_3$ (d) $^3S_1$

28. In the vector model of angular momentum applied to atoms, what is the minimum angle in degrees (in integer) made by the orbital angular momentum vector and the positive Z axis for a $2p$ electron?

29. The non-relativistic Hamiltonian for a single electron atom is $H_0 = \frac{p^2}{2m} - V(r)$
where $V(r)$ is the Coulomb potential and m is the mass of the electron. Considering the spin orbit interaction term $H' = \frac{1}{2m^2c^2}\frac{1}{r}\frac{dV}{dr}\vec{L}\cdot\vec{S}$ added to H_0, which of the following statement is/are true? **[GATE 2024]**
(a) H' commutes with L^2
(b) H' commutes with L_Z and S_Z
(c) For a given value of principal quantum number n and orbital angular momentum quantum number l, there are $2(2l+1)$ degenerate eigenstates of H_0
(d) H_0, L^2, S^2, L_z and S_Z have a set of simultaneous eigenstates

30. The spin-orbit interaction in a hydrogen-like atom is given by the Hamiltonian $H' = -k\vec{L}\cdot\vec{S}$ where k is a real constant. The splitting between levels $^2p_{3/2}$ and $^2p_{1/2}$ due to this interaction is **[GATE 2024]**
(a) $\frac{1}{2}k\hbar^2$ (b) $\frac{3}{2}k\hbar^2$
(c) $\frac{3}{4}k\hbar^2$ (d) $2k\hbar^2$

- **JEST PYQ**

1. If hydrogen atom is bombarded by energetic electrons, it will emit **[JEST 2014]**
(a) $K_\alpha X$ - Rays
(b) β-rays
(c) Neutrons
(d) none of the above

2. The wavelength of red helium-neon laser in air is 6328 A. What happens to its frequency in glass that has a refractive index of 1.50? **[JEST 2015]**
(a) Increases by a factor of 3
(b) Decreases by a factor of 1.5
(c) Remains the same
(d) Decreases by a factor of 0.5

3. Which of the following statements is true for the energies of the terms of the carbon atom in the ground state electronic configuration $1s^2 2s^2 2p^2$? **[JEST 2015]**
(a) $^3P < {}^1D < {}^1S$ (b) $^3P < {}^1S < {}^1D$
(c) $^3P < {}^1F < {}^1S$ (d) $^3P < {}^1F < {}^1D$

4. Which of the following excited states of a hydrogen atom has the highest lifetime? **[JEST 2015]**
(a) $2p$ (b) $2s$ (c) 3 s (d) $3p$

5. The energy difference between the $3p$ and $3s$ levels in Na is 2.1eV. Spin-orbit coupling splits the $3p$ level, resulting in two emission lines differing by 6Å. The splitting of the $3p$ level is approximately, **[JEST 2015]**
(a)2eV (b) 0.2eV
(c) 0.02eV (d) 2meV

6. Consider a hypothetical world in which the electron has spin $\frac{3}{2}$ instead of $\frac{1}{2}$. What will be the electronic configuration for an elemet with atomic number $Z = 5$? **[JEST 2019]**

(a) $1s^4, 2s^1$ (b) $1s^2, 2s^2, 2p^1$
(c) $1s^5$ (d) $1s^3, 2s^1, 2p^1$

- **TIFR PYQ**

1. The spectra of electromagnetic radiation emitted by distant objects like stars and galaxies give important clues about their physical properties. In this context, a correct statement is that **[TIFR -2011]**
(a) the nuclear structure of the distant objects cannot be determined from lines in the visible region of the spectrum
(b) absorption lines in the spectra of distant objects do not carry information about their motion in a direction transverse to the line of sight
(c) the wavelengths in the emission spectrum of an element in a star are always the same as those found in laboratory experiments
(d) absorption spectra cannot be used to determine which molecules are present in the distant objects

2. The ground state electronic configuration for a carbon atom is $(1s)^2(2s)^2(2p)^2$.
The first excited state of this atom would be achieved by **[TIFR -2014]**
(a) re-alignment of the electron spins within the $2p$ orbital.
(b) transition of an electron from the $2s$ orbital to the $2p$ orbital.
(c) transition of an electron from the $2p$ orbital to the $3s$ orbital.
(d) transition of an electron from the $2s$ orbital to the $3s$ orbital.

3. In the ground state electronic configuration of nitrogen ($^{14}_{7}$ N) the L, S and J quantum numbers are **[TIFR 2015]**
(a) $L = 1, S = \frac{1}{2}, J = \frac{1}{2}$
(b) $L = 1, S = \frac{1}{2}, J = \frac{3}{2}$
(c) $L = 0, S = \frac{1}{2}, J = \frac{1}{2}$
(d) $L = 0, S = \frac{3}{2}, J = \frac{3}{2}$

4. In a semiclassical approach, the Hamiltonian of a He atom is modified by adding a magnetic interaction term between the two electrons, of the form $H_1 = A_2 \vec{S}_1 \cdot \vec{S}_2$
Where $\vec{S}_1$ and $\vec{S}_2$ are the electron spins and A_2 is a coupling constant. This leads, for the configuration $1s^2$, to the energy shift **[TIFR 2022]**
(a) $-3A_2/4$ (b) $+3A_2/4$
(c) $+A_2/4$ (d) $-3A_2/4$

- **OTHER EXAM PYQ**

1. The two possible orientations of $\vec{S}$ with respect to an external magnetic field $\vec{B}$ along z-axis, are
(a) $\cos^{-1}\left(\pm\frac{1}{\sqrt{2}}\right)$ (b) $\cos^{-1}\left(\pm\frac{1}{\sqrt{3}}\right)$
(c) $\cos^{-1}\left(\pm\frac{1}{3}\right)$ (d) $\cos^{-1}\left(\pm\frac{1}{2}\right)$

2. The magnitude of magnetic dipole moment corresponding to spin of an electron is
(a) μ_B (b) $2\mu_B$ (c) $\sqrt{2}\mu_B$ (d) $\sqrt{3}\mu_B$

3. A beam of electrons (each of rest mass m, charge e) enters in a uniform magnetic field B along z-axis. The energy separation between the electrons having spin parallel and anti-parallel with magnetic field, is
(a) $\frac{eB\hbar}{m}$ (b) $\frac{eB\hbar}{2m}$ (c) $\frac{eBh}{4m}$ (d) 0

4. The number of possible spectroscopic terms of a one electron atom corresponding to $n = 4$ is
(a) 3 (b) 5 (c) 7 (d) 9

5. The angle between the orbital angular momentum and spin angular momentum for the term $^2D_{3/2}$ is
(a) 45° (b) 62° (c) 90° (d) 135°

6. Which of the following spectroscopic term is not allowed?
(a) $^2D_{3/2}$ (b) $^2F_{5/2}$
(c) $^{-2}P_{3/2}$ (d) $^2D_{1/2}$

7. Consider the state in which $l = 4, s = 1/2$. The orientation of total angular momentum w.r.t z-axis for the state with largest possible j, m_j, is
(a) 25.2° (b) 39.8°
(c) 51. 2° (d) 74.8^0

8. Which of the following statements is NOT CORRECT?
The difference of spin-orbit correction to energy between the spin-down and spin-up electron in a hydrogen like atom will
(a) increase with increase in atomic number.
(b) decrease with the principal quantum number
(c) increase with principal quantum number
(d) decrease with orbital quantum number

9. The number of allowed transitions in the fine structure of H_α line is
(a) 3 (b) 4 (c) 5 (d) 7

10. Find the ground state term of the following atoms:
(a) $^{14}_{7}$ N (b) $^{12}_{6}C$ (c) $^{16}_{8}$O (d) $^{24}_{11}$Na
(e) C^* (f) Na.

11. The electronic configuration of $_{25}Mn$ atom is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^2$.. The ground state term of Mn atom will be
(a) $^6S_{5/2}$ (b) $^6P_{5/2}$
(c) $^1S_0$ (d) $^3P_0$

12. The ground state term of Mn^{3+} ion will be
(a) $^5D_0$ (b) $^5D_4$
(c) $^6S_{5/2}$ (d) $^6P_{5/2}$

13. If the doublet splitting of the first excited state $2^2D_{5/2} - 2^2D_{3/2}$ of $He^+$is 3.67 cm^{-1}, then the corresponding separation of H atom is
(a) 0.23 cm^{-1} (b) 0.36 cm^{-1}
(c) 0.52 cm^{-1} (d) 0.76 cm^{-1}

14. Sodium atom has 11 electrons. If the sequence in which the energy levels are filled in 1 s, 2 s, 2p, 3 s, 3p, 4 s, 3 d... , the ground state of sodium is:
(a) $^3p_{1/2}$ (b) $^2p_{1/2}$
(c) $^1p_{1/2}$ (d) $^2 s_{i/2}$

15. There are four electrons in the $3d$ shell of an isolated atom. The total magnetic moment of the atom in units of Bohr magneton is .....

16. The orbital quantum numbers of two atomic electrons are $\ell_1 = 1$ and $\ell_2 = 2$. The possible values of the total angular momentum quantum number J under LS coupling are
(a) $-1,1$ only (b) 1,2,3 only
(c) 0,1,2,3,4 (d) $-2,-1,0,1,2$

17. Which of the following states exist?
(a) $2\ ^2P_1$ (b) $2\ ^2P_{3/2}$
(c) $2\ ^2P_{5/2}$ (d) $2\ ^2P_{7/2}$

18. Under the LS coupling scheme, the possible spectral terms $^{2s+1}L_J$ for the electronic configuration 2 s3 s are
(a) $^2 S_{1/2}$, $^2P_{3/2}$, $^2P_{1/2}$ (b) $^1 S_0$, $^3P_1$
(c) $^1 S_0$, $^3 S_1$ (d) $^3 S_0$, $^3 S_1$

19. Which of the following is the spectroscopic ground state for Mn^{3+} ions of electronic configuration $1s^2 2s^2 2p^6 3s^2 3p^6 3d^4$ predicted by Hund's rule?
(a) $^5D_0$ (b) $^5D_4$
(c) $^5D_3$ (d) $5D_2$

20. Possible values of the total angular momentum quantum number of a single f-electron are
(a)j $= \frac{7}{2}, \frac{5}{2}$ (b)$j = \pm 3,2,1,0$
(c)j $= \pm\frac{7}{2} \cdot \pm\frac{5}{2}$ (d) None of these

21. The electronic configuration (np) ^{2} can have only which one of the following term
(a) ^{2}D, ^{3}P or ^{1} S (b) ^{1}D, ^{3}P or's
(c) ^{3}D, ^{3}P or ^{2} S (d) None of these

22. Which of the following has the order of increasing energy?
(a) $^1D_2$, $^3D_2$, $^3 F_2$ (b) $^3 F_2, 3D_2, 1D_2$
(c) $^3D_2$, F_2, D_2 (d) $^1D_2$, $^3 F_2$, $^3D_2$

23. The electronic configuration of the ground state of the Na atom is $^2S_{1/2,}$. This implies that
(a) $S = 2, L = 0, J = 2$
(b) $S = 0, L = 1/2, J = 1/2$
(c) $S = 1/2, L = 0, J = 1/2$
(d) $S = 0, L = 2, J = 2$

24. The term symbol for a particular atomic state is $^4P_{5/2}$. The values of S (spin angular momentum), L (orbital angular momentum), J (total angular momentum) of the state are
(a)$S = \frac{3}{2}, L = 0, J = \frac{3}{2}$
(b)$S = \frac{1}{2}, L = 1, J = \frac{3}{2}$
(c)$S = \frac{1}{2}, L = 2, J = \frac{5}{2}$
(d)$S = \frac{3}{2}, L = l, J = \frac{5}{2}$

25. The L, S and J quantum numbers corresponding to the ground state electronic configuration of Boron(Z = 5) are
(a) $L = I, S = \frac{1}{2}, J = \frac{3}{2}$
(b) $L = I, S = \frac{1}{2}, J = \frac{1}{2}$
(c)$L = I, S = \frac{3}{2}, J = \frac{1}{2}$
(d)$L = 0, S = \frac{3}{2}, J = \frac{3}{2}$

26. If an atom is in the $^3D_3$ state, the angle between its orbital and spin angular momentum vectors ($\vec{L}$ and $\vec{S}$) is:

(a) $\cos^{-1}\frac{1}{\sqrt{3}}$ (b) $\cos^{-1}\frac{2}{\sqrt{3}}$

(c) $\cos^{-1}\frac{1}{2}$ (d) $\cos^{-1}\frac{\sqrt{3}}{2}$

27. The Helium atom is excited into the is 2 s configuration. The following spectral terns $^{2\,s+1}$ L are the only ones allowed

(a) ^{1} S, ^{1}P (b) ^{1} S, ^{3}P

(c) ^{1} S, ^{3}S (d) ^{2} S, ^{2}P

28. The possible values of the total angular momentum J resulting from the addition of two angular momenta $J_1 = 1$ and $J_2 = 2$ are

(a) 1.2 (b) 1,3 (c) 0,1,2 (d) 1,2,3

29. In a hydrogen atom, the accidental or Coulomb degeneracy for the $n = 4$ state is:

(a) 4 (b) 16 (c) 18 (d) 32

30. One Bohr magneton is approximately

(a) 10^{23}Am^2 (b) 10^{-23}Am^2

(c) 10^{10}Ain^2 (d) 10^{-10}Am^2

31. The magnetic moment associated with the first orbit in hydrogen atom is given by

(a) $\frac{h}{4\pi me}$ (b) $\frac{4\pi me}{he}$

(c) $\frac{\text{eh}}{4\pi\text{m}} \times \sqrt{3}$ (d) $\frac{ehm}{4\pi}$

32. The spatial part of a two-electron state is symmetric under exchange. If $|\uparrow\rangle$ and $|\downarrow$ represent spin-up and spin-down states respectively of each particle, the spin-part of the two-particle state is

(a) $|\uparrow\rangle|\uparrow\rangle$

(b) $|\uparrow\rangle|\downarrow\rangle$

(c) $|\downarrow\rangle|\uparrow\rangle - |\uparrow\rangle|\downarrow\rangle/\sqrt{2}$

(d) $|\downarrow\rangle|\uparrow\rangle + |\uparrow\rangle|\downarrow\rangle/\sqrt{2}$

33. The ground state electronic configuration for a carbon atom is $(1s)^2(2s)^2(2p)^2$

The first excited state of this atom would be achieved by

(a) re-alignment of the electron spins within the $2p$ orbital

(b) transition of an electron from the 2 s orbital to the 2p orbital.

(c) transition of an electron from the $2p$ orbital to the 3 s orbital

(d) transition of an electron from 2 s orbital to the 3 s orbital.

ANSWER KEY

CSIR-NET PYQ

1-D	2-A	3-B	4-C	5-C
6-A	7-D	8-A	9-B	10-D
11- C	12- D	13-A	14-D	15-A
16-C	17-B	18-		

GATE PYQ

1-B	2-B	3-B	4-C	5-A
6-D	7-D	8-A	9-C	10-B
11-B	12-D	13-A	14-B	15-B
16-A	17-12	18-B	19-D	20-3.612
21-3	22-4	23- C,D		24- 32-93
25-B	26-D	27-A	28-45	29-A,C,D
30-B	31-	32-	33-	

JEST PYQ

1-A	2-C	3-A	4-B	5-D
6-A				

TIFR PYQ

1-B	2-A	3-D	4-A

OTHER EXAM PYQ

1-B	2-D	3-A	4-C	5-D
6-D	7-A	8-C	9-D	10-
11-A	12-A	13-A	14-D	15-0
16-C	17-B	18-C	19-A	20-A
21-B	22-B	23-C	24-D	25-B
26-A	27-C	28-D	29-B	30-B
31-C	32-C	33-A		

❖ Atomic Spectra , (Zeeman Effect, Hyperfine structure)

- **CSIR-NET PYQ**

1. If the hyperfine interaction in an atom is given by $H = a\vec{S}_e \cdot \vec{S}_p$ Where $\vec{S}_e$ and $\vec{S}_p$ denote the electron and proton spins, respectively, the splitting between the $^3S_1$ and $^1S_0$ state is **[CSIR-DEC 2011]**

(a) $a\hbar^2/\sqrt{2}$ (b) $a\hbar^2$
(c) $a\hbar^2/2$ (d) $2a\hbar^2$

2. The spectral line corresponding to an atomic transition from $J = 1$ to $J = 0$ states split in a magnetic field of 1KG into three components seperated by 1.6×10^{-3}Å. If the zero field spectral line corresponding to 1849Å, what is the g-factor corresponding to the $J = 1$ state? (You may use $\frac{hc}{\mu_0} \approx 2 \times 10^4$ cm.) **[CSIR-JUNE 2012]**

(a) 2 (b) 3/2
(c) 1 (d) 1/2

3. The spectroscopic symbol for the ground state of $_{13}$AI is $^2P_{1/2}$. Under the action of a strong magnetic field (when L-S coupling can be neglected) the ground state energy level will split into **[NET Dec. 2013]**

(a) 3 levels (b) 4 levels
(c) 5 levels (d) 6 levels

4. A spectral line due to a transition from an electronic state p to an s state splits into three Zeeman lines in the presence of a strong magnetic field. At intermediate field strengths the number of spectral lines is **[NET June 2014]**

(a) 10 (b) 3 (c) 6 (d) 9

5. An atomic transition $^1P \rightarrow {}^1S$ in a magnetic field 1 Tesla shows Zeeman splitting. Given that the Bohr magneton $\mu_B = 9.27 \times 10^{-24}$ J/T, and the wavelength corresponding to the transition is 250 nm, the separation in the Zeeman spectral lines is approximately **[NET Dec. 2014]**

(a) 0.01 nm (b) 0.1 nm
(c) 1.0 nm (d) 10 nm

6. In a normal Zeeman effect experiment using a magnetic field of strength 0.3 T, the splitting between the components of a 660 nm spectral line is **[NET June 2016]**

(a) 12pm (b) 10pm
(c) 8pm (d) 6pm

7. The total spin of a hydrogen atom is due to the contribution of the spins of the electron and the proton. In the high temperature limit, the ratio of the number of atoms in the spin-1 state to the number in the spin 0 state is **[NET Dec. 2016]**

(a) 2 (b) 3 (c) ½ (d) 1/3.

8. An atomic spectral line is observed to split into nine components due to Zeeman shift. If the upper state of the atom is $^3D_2$ then the lower state will be **[NET June 2017]**

(a) $^3F_2$ (b) $^3F_1$
(c) $^3p_1$ (d) $^3p_2$

9. The Zeeman shift of the energy of a state with quantum numbers L, S, J and m_J is

$$H_Z = \frac{m_J \mu_B B}{J(J+1)}(\langle L \cdot J\rangle + g_S\langle S \cdot J\rangle)$$

where B is the applied magnetic field, g_S is the g-factor for the spin and $\mu_B/h = 1.4\text{MHz} - \text{G}^{-1}$, where h is the Planck constant. The approximate frequency shift of the $S = 0, L = 1$ and $m_J = 1$ state, at a magnetic field of 1G, is **[NET Dec. 2017]**

(a) 10MHz (b) 1.4MHz

(c) 5MHz (d) 2.8MHz

10. The ground state of sodium atom (^{11}Na) is a $^{2}S_{1/2}$ state. The difference in energy levels arising in the presence of a weak external magnetic field B, given in terms of Bohr magneton, μ_B, is **[NET Dec. 2017]**
(a) $\mu_B B$ (b) $2\mu_B B$
(c) $4\mu_B B$ (d) $6\mu_B B$

11. If the bindings energies of the electron in the K and L shells of silver atom are 25.4keV and 3.34keV, respectively, then the kinetic energy of the Auger electron will be approximately **[NET June 2017]**
(a) 22keV (b) 9.3keV
(c) 10.5keV (d) 18.7keV

12. The mean kinetic energy per atom in a sodium vapors lamp is 0.33eV. Given that the mass of sodium atom is approximately 22.5×10^9eV, the ratio of the Doppler width of an optical line to its central frequency is **[NET Dec. 2019]**
(a) 7×10^{-7} (b) 6×10^{-6}
(c) 5×10^{-2} (d) 4×10^{-4}

13. If we take the nuclear spin I int ρ account; the total angular momentum is $\vec{F} = \vec{L} + \vec{S} + \vec{I}$, where $\vec{L}$ and $\vec{S}$ are the orbital and spin angular momenta ofthe electron. Whe Hamiltonian of the hydrogen atom is corrected by the additional interaction $\lambda\vec{I}(\vec{L} + \bar{S})$, where $\lambda > 0$ is a constant. The total angular momentum quantum number F of the p-orbital state with the lowest energy is **[NET Nov. 2020]**
(a) 0 (b) 1 (c) ½ (d) 3/2

14. The red line of wavelength 644 nm in the emission spectrum of Cd corresponds to a transition from the $^{1}D_2$ level to the $^{1}P_1$ level. In the presence of a weak magnetic field, this spectral line will split into (ignore hyperfine structure) **[NET June. 2023]**
(a) 9 lines (b) 6 lines
(c) 3 lines (d) 2 lines

15. A solar probe mission detects a fractional wavelength shift ($\Delta\lambda/\lambda$) of the spectral line $\lambda =$ 630 nm within a sunspot to be of the order of 10^{-5}. Assuming this shift is caused by the normal Zeeman effect (i.e., neglecting other physical effects), the estimated magnetic field (in tesla) within the observed sunspot is closest to **[NET Dec. 2023]**
(a) 3×10^{-5} (b) 300
(c) 0.3 (d) 3×10^{5}

- **GATE PYQ**

1. The number of hyperfine components observed in the electronic transition $^{2}p_{L/2} \rightarrow {}^{2}S_{L/2}$ of an atom with nuclear spin $\frac{1}{2}$ is **[GATE 2001]**
(a) 3 (b) 4
(c) 6 (d) 5

2. The total number of Zeeman components observed in an electronic transition $^{2}D_{5/2} \rightarrow {}^{2}P_{3/2}$ of an atom in a weak field is **[GATE 2001]**
(a) 4 (b) 6
(c) 12 (d) 10

3. The hyperfine splitting of the spectral lines of an atom is due to **[GATE 2003]**
(a) the coupling between the spins of two or more electrons
(b) the coupling between the spins and the orbital angular momenta of the electrons
(c) the coupling between the electron spins and the nuclear spin
(d) the effect of external electromagnetic fields

4. In the presence of an inhomogeneous weak magnetic field, spectral lines due to transitions between two sets of states were observed
(1) $^{5}l_5 \rightarrow {}^{5}H_4$ and (2) $^{2}D_{5/2} \rightarrow {}^{2}P_{3/2}$
The types of Zeeman effect observed in (1) and (2) respectively are **[GATE 2003]**
(a) normal, normal
(b) anomalous, anomalous
(c) anomalous, normal
(d) normal, anomalous

5. The number of levels into which each of the above four terms split into respectively is **[GATE 2003]**
(a) 6,4,10,8 (b) 4, 6, 10, 12
(c) 11,9,6,4 (d) 9,5,12,10

6. Assuming that the L-S coupling scheme is valid, the number of permitted transitions from $^{2}P_{3/2}$ to $^{2}S_{1/2}$ due to a weak magnetic field is **[GATE 2004]**
(a) 2 (b) 4
(c) 6 (d) 10

7. The sodium doublet lines are due to transitions from $^{2}P_{3/2}$ and $^{2}P_{1/2}$ levels to $^{2}S_{1/2}$ level. On application of a weak magnetic field, the total number of allowed transitions becomes

[GATE 2005]

(a) 4 (b) 6 (c) 8 (d) 10

8. . In hyperfine interaction, there is coupling between the electron angular momentum $\vec{J}$ and nuclear angular momentum $\vec{I}$, forming resultant angular momentum $\vec{F}$. The selection rules for the corresponding quantum number F in hyperfine transitions are ` **[GATE 2006]**

(a) $\Delta F = \pm 2$ only (b) $\Delta F = \pm 1$ only

(c) $\Delta F = 0, \pm 1$ (d) $\Delta F = \pm 1, \pm 2$

9. The D_1 and D_2 lines of $Na(3^2P_{1/2} \rightarrow 3^2 S_{1/2}, 3^2P_{3/2} \rightarrow 3^2 S_{1/2})$ will split on the application of a weak magnetic field into **[GATE 2007]**

(a) 4 and 6 lines respectively

(b) 3 lines each

(c) 6 and 4 lines respectively

(d) 6 lines each

10. The hyperfine structure of $Na(3^2P_{3/2})$ with nuclear spin $I = 3/2$ has **[GATE 2007]**

(a) 1 state (b) 2 states

(c) 3 states (d) 4 states

11. Cesium has a nuclear spin of $\frac{7}{2}$, the hyperfine spectrum of the D lines of the cesium atom will consist of **[GATE 2009]**

(a) 10 lines (b) 4 lines

(c) 6 lines (d) 14 lines

Common Data for Questions 12 and 13:

Consider the Zeeman splitting of single electron system for the $3d \rightarrow 3p$ electric dipole transition.

12. The Zeeman spectrum is **[GATE 2009]**

(a) randomly

(b) only π polarized

(c) only σ polarized

(d) both π and σ polarized

13. The fine structure line having the longest wave length will split into **[GATE 2009]**

(a) 17 components (b) 10 components

(c) 8 components (d) 4 components

14. The spectral line corresponding to the transition

$$^2P_{1/2}\left(m_j = +\frac{1}{2}\right) \rightarrow {}^1S_{1/2}\left(m_j = -\frac{1}{2}\right)$$

Is observed along the direction of the applied magnetic field. The emitted electromagnetic field is **[GATE 2010]**

(a) Circularly polarized

(b) Linearly polarized

(c) Unpolarized

(d) Not emitted along the magnetic field Direction

15. In the presence of a weak magnetic field, atomic hydrogen undergoes the transition: $^2p_{1/2} \rightarrow {}^2 s_{1/2}$ by emission of radiation. The number of distinct spectral lines that are observed in the resultant Zeeman spectrum is **[GATE 2010]**

(a) 2 (b) 3 (c) 4 (d) 6

16. An atom with one outer electron having orbital angular momentum l is placed in a weak magnetic field. The number of energy levels into which the higher total angular momentum state splits, is **[GATE 2011]**

(a) $2\ell + 2$ (b) $2\ell + 1$

(c) 2ℓ (d) $2\ell - 1$

17. In a normal Zeeman effect experiment, spectral splitting of the line at the wavelength 643.8 nm corresponding to the transition $5^1D_2 \rightarrow 5^1P_1$ of cadmium atom is to be observed. The spectrometer has a resolution of 0.01nM. The minimum magnetic field needed to observe this is ($m_e = 9.1 \times 10^{-31}$ kg, $e = 1.6^{-19}$C, $c = 3 \times 10^8$ m/s) **[GATE 2013]**

(a) 0.26 T (b) 0.52 T

(c) 2.6 T (d) 5.2 T

18. The number of spectral lines allowed in the spectrum for the $3^2D \rightarrow 3^2P$ transitions in sodium are..... **[GATE 2013]**

19. The number of normal Zeeman splitting components of $^1P \rightarrow {}^1D$ transition is **[GATE 2014]**

(a) 3 (b) 4 (c) 8 (d) 9

20. The emission wavelength for the transition $^1D_2 \rightarrow {}^1F_3$ is $3122\dot{A}$. The ratio of populations of the final to the initial states at a temperature 5000 K is ($h = 6.626 \times 10^{-34}$ J.s, $c = 3 \times 10^8$ m/s, $k_B = 1.380 \times 10^{-23}$ J/k) **[GATE 2014]**

(a) 2.03×10^{-5} (b) 4.02×10^{-5}
(c) 7.02×10^{-5} (d) 9.83×10^{-5}

21. The number of permitted transitions from $^2P_{3/2} \rightarrow {}^2S_{1/2}$ in the presence of a weak magnetic field is **[GATE 2015]**

22. An atom in its single state is subjected to a magnetic field. The Zeeman splitting of its 650 nm spectral lines is 0.03 nm. The magnitude of the field is Tesla (up to two decimal places). $[e = 1.60 \times 10^{-19}\text{C}, m_e = 9.11 \times 10^{-31}\text{ kg}, c = 3.0 \times 10^8\text{ ms}^{-1}]$ **[GATE 2018]**

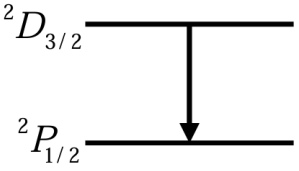
23. Match the physical effects and order of magnitude of their energy scales given below, where $\alpha = \frac{e^2}{4\pi\epsilon_0\hbar c}$ is fine structure constant; m_e and m_p are electron and proton mass, respectively. **[GATE 2018]**

Group I	Group II
P: Lamb shift	1: $\sim O(\alpha^2 m_e c^2)$
Q: Fine structure	2: $\sim O(\alpha^4 m_e c^2)$
R: Bohr energy	3: $\sim O(\alpha^4 m_e^2 c^2/m_p)$
S: Hyperfine structure	4: $\sim O(\alpha^5 m_e c^2)$

(a) P-3, Q-1, R-2, S-4 (b) P-2, Q-3, R-1, S-4
(c) P-4, Q-2, R-1, S-3 (d) P-2, Q-4, R-1, S-3

24. A hydrogenic atom is subjected to a strong magnetic field. In the absence of spin-orbit coupling, the number of doubly degenerate states created out of the d-level is…….. **[GATE 2020]**

25. The transition line, as shown in the figure, arises between $^2D_{3/2}$ and $^2P_{1/2}$ states without any external magnetic field. The number of lines that will appear in the presence of a weak magnetic field (in integer) is **[GATE 2021]**



26. The spin $\vec{S}$ and orbital angular momentum $\vec{L}$ of an atom precess about $\vec{J}$, the total angular momentum. $\vec{J}$ precesses about an axis fixed by a magnetic field $\vec{B}_1 = 2B_0\hat{z}$, where B_0 is a constant. Now, the magnetic field is changed to $\vec{B}_2 = B_0(\hat{x} + \sqrt{2}\hat{y} + \hat{z})$. Given the orbital angular momentum quantum number $l = 2$ and spin quantum number $s = 1/2$, θ is the angle between $\vec{B}_1$ and $\vec{J}$ for the largest possible values of total angular quantum number j and its z-component j_z. The value of θ (in degree, rounded off to the nearest integer) is…….. **[GATE 2021]**

27. For normal Zeeman lines observed ∥ and ⊥ to the magnetic field applied to an atom, which of the following statements are true?
(a) Only π-lines are observed I| to the field
(b) σ-lines ⊥ to the field are plane polarized
(c) π-lines ⊥ to the field are plane polarized
(d) Only σ-lines are observed ∥ to the field
[GATE 2022]

28. An atom is subjected to a weak uniform magnetic field $\vec{B}$. The number of lines in its Zeeman spectrum for transition from $n = 2, l = 1$ to $n = 1, l = 0$ is **[GATE 2024]**
(a) 8 (b) 10 (c) 12 (d) 5

- **JEST PYQ**

1. A continuous monochromatic ($\lambda = 600$ nm) laser beam is chopped into 0.1 ns pulses using some sort of shutter. Find the resultant linewidth $\Delta\lambda$ of the beam in units of 10^{-3} nm. = **[JEST 2016]**

- **TIFR PYQ**

1. When a pure element is vaporized and placed in a uniform magnetic field B_0, it is seen that a particular spectral line of wavelength l, corresponding to $J = 1\vec{J} = 0$ transition, gets split into three components $\lambda, \lambda \pm \Delta\lambda$. It follows that the Lande g-factor for the transition $J = 1\ \vec{J} = 0$ is given by **[TIFR 2013]**

(a) $g = \frac{hc}{\mu_B B_0}\frac{\Delta\lambda^2}{\lambda}$ (b) $g = \frac{hc}{\mu_B B_0}\frac{\lambda^2}{\Delta\lambda}$

(c) $g = \frac{hc}{\mu_B B_0}\frac{\lambda}{\Delta\lambda^2}$ (d) $g = \frac{hc}{\mu_B B_0}\frac{\Delta\lambda}{\lambda}$

2. The number of hyperfine states found in the He^3 atom for the electronic configuration

$1s^1 2s^0 2p^1$ would be **[TIFR 2023]**

(a) 7 (b) 2 (c) 4 (d) 1

- **OTHER EXAM PYQ**

1. A sample of certain element is placed in a magnetic field $\vec{B}$. The wavelength separation between the Zeeman components of a spectral line of wavelength λ will be

(a) $\frac{\mu_B B}{hc}\lambda$ (b) $\frac{\mu_B B}{hc\lambda}$

(c) $\frac{hc\lambda}{\mu_B B}$ (d) $\frac{\mu_B B}{hc}\lambda^2$

2. In the presence of external weak magnetic field, the number of substates into which the state $^2D_{5/2}$ will split, is

(a) 3 (b) 4 (c) 5 (d) 6

3. In the presence of weak magnetic field B, the separation between the splitted sublevels of the $^3D_2$ level will be

(a) $\frac{7eB}{24\pi mc}$ (b) $\frac{7eB}{12\pi mc}$

(c) $\frac{7eB}{6\pi mc}$ (d) none of these

4. The number of Zeeman components for $^2D_{3/2} - {}^2P_{3/2}$ transition in one-electron atom will be

(a) 6 (b) 8 (c) 10 (d) 12

5. The Zeeman pattern of a line consists of six equidistant components. The upper state term is know to be $^2P_{3/2}$. The lower state term will be

(a) $^1P_1$ (b) $^2S_{1/2}$

(c) $^1S_0$ (d) none of these

6. The sodium doublet lines are due to transitions from $^2P_{3/2}$ and $^2P_{1/2}$ levels to $^2S_{1/2}$ level. On application of a weak magnetic field, the total number of the allowed transitions are

(a) 4 (b) 6 (c) 8 (d) 10

7. The total number of Zeeman components observed in an electronic transition $^2\mathrm{D}_{5/2} \rightarrow {}^2\mathrm{P}_{3/2}$ of an atom in a weak field is:

(a) 4 (b) 6 (c) 12 (d) 10

Common data for Q.8 and Q.9

In the presence of an inhomogeneous weak magnetic field, spectral lines due to transitions between two sets of states were observed.

(1) $^5\mathrm{I}_5 \rightarrow {}^5\mathrm{H}_4$ and (2) $^2\mathrm{D}_{5/2} \rightarrow {}^2\mathrm{P}_{3/2}$

8. The number of levels into which each of the above four terms split into respectively is:

(a) 6,4,10,8 (b) 4, 6, 10, 12

(c) 11,9,6,4 (d) 9, 5, 12, 10

9. The D_1 and D_2 lines of Na atom will split on the application of a weak magnetic field into

(a) 4 and 6 lines (b) 3 lines each

(c) 6 and 4 lines (d) 6 lines each

Common Data Q. 10 and Q. 12

Consider the Zeeman splitting of a single electron system for the 3 d → 3p electric dipole transition.

10. The number of distinct spectral lines that are observed in the resultant Zeeman spectrum is

(a) 2 (b) 3 (c) 4 (d) 6

11. The spectral line corresponding to the transition $2P\_1/2(m,=+1/2) \rightarrow 2s\_1/2(= m\_J = -1/2)$ is observed along the direction of the applied magnetic field. The emitted electromagnetic field is:

(a) Circularly polarized

(b) Linearly polarized

(c) Unpolarized

(d) Not emitted along the magnetic field direction

12. The D1 and D2 lines of $\mathrm{Na}\left(3^2\mathrm{P}_{1/2} \rightarrow 3^2\,\mathrm{S}_{1/2}, 3^2\mathrm{P}_{3/2} \rightarrow 3^2\,\mathrm{S}_{1/2}\right)$ will split on the application of a weak magnetic field into

(a) 4 and 6 lines respectively

(b) 3 lines each

(c) 6 and 4 lines respectively

(d) 6 lines each

13. In Zeeman effect, a spectral-line, upon the application of magnetic field, splits into more than three components because of

(a) Energy levels split into $2\,\mathrm{J} + 1$

(b) In magnetic field $\Delta \mathrm{m_J} = 0, \pm 1$ no longer holds

(c) Variation of Lande g-factor from one level to another

(d) None of the above

14. In the Zeeman effect the light emitted along and perpendicular to the applied magnetic field are respectively

(a) linearly and circularly polarized

(b) circularly and linearly polarized
(c) both linearly polarized
(d) both circularly polarized

15. Given the following table,

Group-I	Group-II
P. Stem-Gerlach experiment	**1**.Wave nature of particles
Q. Zeeman effect	**2**.Quantization of energy of electrons in the atoms
R. Frank-Hertz experiment	**3**.Existence of electron spin
S. Davisson-Germer Experiment	**4.**Space quantization of angular momentum

Which one of the following correctly matches the experiments from Group-I to their inferences in Group-II ?
(a) P-2, Q-3, R-4, S-1
(b) P-1, Q-3, R-2, S-4
(c) $P-3, Q-4, R-2, S-1$
(d) P-2, Q-1, R-4, S-3

16. The number of components in the hyperfine structure corresponding to the spectral line due to the transition $^2D_{3/2} \rightarrow {}^2P_{1/2}$ within a certain atom (having nuclear spin $I = 9/2$), is
(a) 4 (b) 6 (c) 8 (d) 10

Common Data for Q. 17 and Q. 18
A certain atom has a excited state $^2D_{5/2}$, which splits into six hyperfine levels. The distance between the two consecutive hyperfine levels are $0.236\ cm^{-1}, 0.312\ cm^{-1}, 0.391\ cm^{-1}$, $0.471\ cm^{-1}, 0.551\ cm^{-1}$ respectively.

17. The nuclear spin quantum number of the atom is
(a) ½ (b) 3/2 (c) 7/2 (d) 9/2

18. The hyperfine structure constant of the molecule is
(a) $0.039\ cm^{-1}$ (b) $0.078\ cm^{-1}$
(c) $0.098\ cm^{-1}$ (d) $0.112\ cm^{-1}$

19. The number of hyperfine components observed in the electronic transition $^2p_{1/2} \rightarrow {}^2S_{1/2}$ of an atom with nuclear spin 1/2 is:
(a) 3 (b) 4 (c) 6 (d) 5

20. The hyperfine splitting of the spectral lines of an atom is due to :
(a) The coupling between the spins of two or more electron
(b) The coupling between the spins and the orbital angular momenta of the electron
(c) The coupling between the electron spins and the nuclear spin
(d) The effect of external electromagnetic field

21. The hyperfine structure of $Na(3^2P_3)$ with nuclear spin $I = 3/2$ has
(a) 1 state (b) 2 states
(c) 3 states (d) 4 states

22. In hyperfine interaction, there is coupling between the electron angular momentum $\vec{J}$ and nuclear angular momentum $\vec{I}$, forming resultant angular momentum $\vec{F}$. The selection rules for the corresponding quantum number F in hyperfine transitions are
(a) $\Delta F = \pm 2$ only (b) $\Delta F = \pm 1$ only
(c) $\Delta F = 0, \pm 1$ (d) $\Delta F = \pm 1, \pm 2$

23. Cesium has a nuclear spin of $7/2$. The hyperfine spectrum of the D lines of the Cesium atom will consist of
(a) 10 lines (b) 4 lines
(c) 6 lines (d) 14 lines

24. The wavelength of a photon emitted from a moving source is appeared to be 500.1 nm, whereas the actual wavelength is 500 nm. The speed and direction of the movement of the source w.r.t the observer is
(a) 30 km/sec, away from the observer
(b) 60 km/sec, away from the observer
(c) 30 km/sec, towards the observer
(d) 60 km/sec, towards the observer

25. The dependence of Doppler broadened line width of a laser transition on temperature T is given by
(a) T (b) $T^{-1/2}$
(c) $T^{1/2}$ (d) T^2

26. The minimum voltage that must be applied to a X-ray tube to produce X-ray photons of wavelength 0.01 nm, is
(a)50KV (b) 75KV
(c) 100KV (d) 125KV

27. If the wavelength limit of the K-series for a certain element is about 0.1 nm, then the atomic number of the element will be
(a) 19 (b) 25 (c) 31 (d) 39

28. The Copper ($Z = 29$) target in an X-ray tube has some impurity in it. In the X-ray spectrum emitted from the tube, there is an additional

line of wavelength 0.54 A^0 alongwith the K_α line of wavelength 1.54 A^0. The impurity present in the target of the X-ray tube may be
(a) Na (b) K (c) Cl (d) Cd

29. The continuous X-ray spectrum is the result of the
(a) Photoelectric effect
(b) Inverse photoelectric effect
(c) Compton effect
(d) Auger effect

30. The energy E of K_αX-rays emitted from targets of different atomic number Z varies as
(a) Z^2 (b) $Z^{2/3}$ (c) Z (d) $Z^{1/2}$

31. Which one of the following would not cause the broadening in spectral lines?
(a) Doppler effect
(b) Heisenberg's uncertainty
(c) Absorption of e.m.radiation
(d) Collisions

32. The linear Stark effect is possible in a hydrogen atom but not in a sodium atom because
(a) The principal quantum number for the ground state of the sodium atom is different from that of the hydrogen atom in the ground state
(b) Spin-orbit interaction is stronger in sodium than in hydrogen
(c) The electronic energy levels of sodium exhibit orbital-degeneracy
(d) The electronic energy levels of hydrogen exhibit orbital-degeneracy

33. Which of the following transitions give rise to the $K_{\alpha 1}$ line of X-ray spectra?
(a) $2\,^2S_{1/2} \rightarrow 1^2S_{1/2}$ (b) $2^2P_{1/2} \rightarrow 1^2\,S_{1/2}$
(c) $2\,^2P_{5/2} \rightarrow 1^2\,S_{1/2}$ (d) $2\,^2P_{3/2} \rightarrow 1\,^2\,S_{1/2}$

34. The normal Zeeman effect is:
(a) Observed only in atoms with an even number of electrons
(b) Observed only in atoms with an odd number of electrons
(c) A confirmation of space quantization
(d) Not a confirmation of space quantization

35. In a Stern-Gerlach experiment the atomic beam whose angular momentum state is to be determined, must travel through
(a) Homogeneous radio frequency magnetic field
(b) Homogeneous static magnetic field
(c) Inhomogeneous static magnetic field
(d) Inhomogeneous radio frequency magnetic field

36. The L_β line of X-rays emitted from an atom with principal quantum numbers $n = 1,2,3, \ldots$ arises from the transition.
(a) $n = 4 \rightarrow n = 2$ (b) $n = 3 \rightarrow n = 2$
(c) $n = 5 \rightarrow n = 2$ (d) $n = 3 \rightarrow n = 2$

37. The principal series of spectral lines of lithium is obtained by transitions between
(a) nS and 2P, $n > 2$ (b) nD and 2P, $n > 2$
(c) nP and 2 S, $n > 1$ (d) nF and 3D, $n > 3$

38. In the linear Stark effect, the application of an electric field
(a) completely lifts the degeneracy of $n = 2$ level on hydrogen atom amd splits $n = 2$ level into four levels
(b) Partially lifts the degeneracy of $n = 2$ level on hydrogen atom amd splits $n = 2$ level into three levels
(c) Partially lifts the degeneracy of $n = 2$ level on hydrogen atom and splits $n = 2$ level into two level
(d) Does not affect the $n = 2$ levels

39. Group I lists some physical phenomena while Group II gives some physical parameters. Match the phenomena with the corresponding parameter.

Group I	Group II
P. Doppler Broadening	1. Moment of inertia
Q. Natural Broadening	2. Refractive index
R. Rotational spectrum	3. Lifetime of the energy level
S. Total internal reflection	4. Pressure

(a) P-4, Q-3, R-1, S-2 (c) P-2, Q-3, R-4, S-1
(b) P-3, Q-2, R-1, S-4 (d) P-1, Q-4, r-2, S-3

40. Cesium has a nuclear spin of 7/2. The hyperfine spectrum of the D lines of the Cesium atom will consist of
(a) 10 lines (b) 4 lines
(c) 6 lines (d) 14 lines

41. The ratio of intensities of the D_1 and D_2 lines of sodium at high temperature
(a) 1: 1 (b) 2: 3 (c) 1: 3 (d) 1: 2

42. As a consequence of the interaction between the electron's orbital angular momentum and the nuclear spin, the $^2\,S_{1/2}$ electronic level of

the hydrogen atom
(a) shifts up by a constant amount
(b) splits into two hyperfine levels
(c) shifts down by a constant amount
(d) splits into three hyperfine levels

43. The electronic energy levels in a hydrogen atom are given by $E_n = -13.6/m^2 eV$. If a selective excitation to the $n = 100$ level is to be made using a laser, the maximum allowed frequency line-width of the laser is
(a) 6.5MHz (b) 6.5GHz
(c) 6.5 Hz (d) 6.5kHz

44. If the wavelength of $K\alpha_2$X-ray line of an element is 1.544Å, then the atomic number (Z) of the element is…..

ANSWER KEY

- **NET PYQ**

1-b	2-c	3-c	4-a	5-a
6-d	7-b	8-c	9-b	10-b
11-d	12-b	13-d	14-c	15-c

- **GATE PYQ**

1-a	2-c	3-c	4-b	5-c
6-c	7-d	8-c	9-a	10-d
11-a	12-d	13-b	14-a	15-c
16-a	17-b	18-3	19-a	20-c
21-6	22-1.52	23-c	24-5	25-6
26-92	27-b,c	28-b		

- **JEST PYQ**

1-1.91

- **TIFR PYQ**

1-d	2-a

- **OTHER EXAM PYQ**

1-d	2-d	3-a	4-c	5-d
6-d	7-c	8-c	9-a	10-c
11-a	12-a	13-c	14-b	15-c
16-b	17-d	18-b	19-a	20-c
21-d	22-c	23-a	24-b	25-c
26-d	27-c	28-d	29-b	30-a
31-c	32-d	33-d	34-c	35-c
36-a	37-c	38-c	39-a	40-a
41-d	42-b	43-c	44-29	

❖ AMP Assignment: Rotational Spectra)

➢ CSIR-NET PYQ

1. The first absorption spectrum of $^{12}C^{26}O$ is at $3.842\ cm^{-1}$ while that of $^{13}C^{16}O$ is at $3.673\ cm^{-1}$. The ratio of their moments of inertia is

[CSIR-JUNE 2012]

(a) 1.851 (b) 1.286
(c) 1.046 (d) 1.038

2. Consider the hydrogen deuterium molecule HD. If the mean distance between the two atoms is 0.08 nm and the mass of the hydrogen atom is $938MeV/c^2$, then the energy difference ΔE between the two lowest rotational states is approximately

[NET June 2013]

(a) $10^{-1}eV$ (b) $10^{-2}eV$
(c) $2\times10^{-2}eV$ (d) $10^{-3}eV$

3. The diatomic molecule HF has an absorption line in the rotational band at $40\ cm^{-1}$ for the isotope ^{18}F. The corresponding line for the isotope ^{19}F will be shifted by approximately

NET Dec. 2018]

(a) $0.05\ cm^{-1}$ (b) $0.11\ cm^{-1}$
(c) $0.33\ cm^{-1}$ (d) $0.01\ cm^{-1}$

4. The absorption lines arising from pure rotational effects of HCl are observed at $83.03\ cm^{-1}, 103.73\ cm^{-1}$, $124.30\ cm^{-1}, 145.03\ cm^{-1}$ and $165.51\ cm^{-1}$. The moment of inertia of the HCl molecule is

$$\left[\text{Take } \frac{h}{2\pi c} = 5.6\times10^{-44}\ \text{kg}-\text{m}\right]$$

[NET Nov. 2020]

(a) $1.1\times10^{-48}\ kg-m^2$
(b) $2.8\times10^{-47}\ kg-m^2$
(c) $2.8\times10^{-48}\ kg-m^2$
(d) $1.1\times10^{-12}\ kg-m^2$

➢ GATE PYQ

1. The pure rotational levels of a molecule in the far-infrared region follows the formula $F(J) = BJ(J+1)$, where F(J) is the energy of the rotational level with quantum number J and B is the rotational constant. The lowest rotational energy gap in rotational Raman spectrum is

[GATE 2001]

(a) 2 B (b) 4 B
(c) 6 B (d) 8 B

2. The rotational lines of the CN band system at 3883.4Å is represented by a formula $\bar{\nu} = (25798 + 3.850\ m\ +0.068\ m^2)cm^{-1}$, where m is a running number. Calculate the values of the rotational constants B_v' and B_v'', the location of the band head and the degradation of the band.

[GATE 2001]

3. Carbon monoxide has a bond length of 0.1132 nm. What will be the frequency of rotation of the molecule for its lowest excited state?

[GATE 2002]

4. Three values of rotational energies of molecules are given below in different units
P $10\ cm^{-1}$
Q 10^{-23} J
R 10^4MHz
Choose the correct arrangement in the increasing order of energy

[GATE 2003]

(a) P, Q, R (b) R, Q, P
(c) R, P, Q (d) Q, R, P

5. Consider the pure rotational spectrum of a diatomic rigid rotor. The separation between two consecutive lines ($\Delta\bar{\nu}$) in the spectrum

[GATE 2004]

(a) is directly proportional to the moment of inertial of the rotor

(b) in inversely proportional to the moment of inertia of the rotor

(c) depends on the angular momentum

(d) is directly proportional to the square of the interatomic separation

6. The typical wavelengths emitted by diatomic molecules in purely vibrational and purely rotational transitions are respectively in the region of

[GATE 2005]

(a) infrared and visible

(b) visible and infrared

(c) infrared and microwave

(d) microwave and infrared

7. In the microwave spectrum of identical rigid diatomic molecules, the separation between the spectral lines is recorded to be 0.7143 cm^{-1}. The moment of inertia of the molecule, in kgm^2, is

[GATE 2006]

(a) 2.3×10^{-36} (b) 2.3×10^{-40}

(c) 7.8×10^{-42} (d) 7.8×10^{-46}

8. The allowed rotational energy levels of a rigid hetero-nuclear diatomic molecule are expressed as $\varepsilon_J = BJ(J+1)$, where B is the rotational constant and J is a rotational quantum number. In a system of such diatomic molecules of reduced mass μ, some of the atoms of one element are replaced by a heavier isotope, such that the reduced mass is changed to 1.05μ. In the rotational spectrum of the system, the shift in the spectral line, corresponding to a transition $J = 4 \rightarrow J = 5$, is

[GATE 2007]

(a) 0.475 B (b) 0.50 B

(c) 0.95 B (d) 1.0B

9. Three consecutive absorption lines at 64.275 cm^{-1}, 77.130 cm^{-1} and 89.985 cm^{-1} have been observed in a microwave spectrum for a linear rigid diatomic molecule. The moments of inertia I_A and I_B are I_A is with respect to the bond axis passing through the centre of mass and I_B is with respect to an axis passing through the centre of mass and perpendicular to bond axis)

[GATE 2008]

(a) both equal to $\frac{h^2}{12.855hc}$ gmcm^2

(b) zero and $\frac{\hbar^2}{12.855hc}$ gmcm^2

(c) both equal to $\frac{\hbar^2}{6.427hc}$ gmcm^2

(d) zero and $\frac{h^2}{6.427hc}$ gmcm^2

10. Group I lists some physical phenomena while group II gives some physical parameters. Match the phenomena with the corresponding parameter.

[GATE 2009]

Group I

P. Doppler Broadening

Q. Natural Broadening

R. Rotational spectrum

S. Total internal reflection

Group II

1. Moment of inertia
2. Refractive index
3. Lifetime of the energy level
4. Pressure

(a) $P-4, Q-3, R-1, S-2$

(b) $P-3, Q-2, R-1, S-4$

(c) $P-2, Q-3, R-4, S-1$

(d) $P-1, Q-4, R-2, S-3$

11. The three principal moments of inertia of a methanol (CH_3OH) molecule have the property $I_x = I_y = I$ and $I_z \neq I$. The rotational energy eigenvalues are

[GATE 2010]

(a) $\frac{\hbar^2}{2I}\ell(\ell+1) + \frac{\hbar^2 m_1^2}{2}\left(\frac{1}{I_z} - \frac{1}{I}\right)$

(b) $\frac{\hbar^2}{2I}\ell(\ell+1)$

(c) $\frac{\hbar^2 m_1^2}{2}\left(\frac{1}{I_z} - \frac{1}{I}\right)$

(d) $\frac{\hbar^2}{2I}\ell(\ell+1) + \frac{\hbar^2 m_1^2}{2}\left(\frac{1}{I_2} + \frac{1}{1}\right)$

12. Match the typical spectra of a stable molecules with the corresponding wave number range

[GATE 2010]

1. Electronic spectra
2. Rotational spectra
3. Molecular spectra

(i) 10^6 cm^{-1} and above

(ii) $10^5 - 10^6$ cm^{-1}

(iii) 108 – 102 cm-1

(a) (1-ii), (2-i), (3-iii)

(b) (1-ii), (2-iii), (3-i)
(c) (1-iii), (2-ii), (3-i)
(d) (1-i), (2-ii), (3-iii)

13. The moment of inertia of a rigid diatomic molecule A is 6 times that of another rigid diatomic molecule B. If the rotational energies of the molecules are equal, then the corresponding values of the roational quantum numbers J_A and J_B are

[GATE 2014]

(a) $J_A = 2, J_B = 1$ (b) $J_A = 3, J_B = 1$
(c) $J_A = 5, J_B = 0$ (d) $J_A = 6, J_B = 1$

14. In a rigid-rotator of mass M, if the energy of the first excited state is 1meV, then the fourth excited state entergy (in meV) is ……..

[GATE 2015]

15. Which one of the following options is the most appropriate match between the items given in Column 1 and Column 2?

[GATE 2023]

Column 1	Column 2
(i) Visible light	P. Transition between core energy levels of atoms
(ii) X-rays	Q. Transition between nuclear energy levels
(iii) Gamma rays	R. Pair production
(iv)Thermal neutrons	S. Crystal structure determination
	T. Photoelectric effect

(a) (i) – T; (ii) – P, S, T; (iii) – Q, R; (iv) – S
(b) (i) – P, T; (ii) – S; (iii) – R, S; (iv) – S, T
I (i) – T; (ii) – R, S; (iii) – Q, R; (iv) – S
(d) (i) – S, T; (ii) – P, S; (iii) – R, T; (iv) - S

16. An atom is subjected to a weak uniform magnetic field $\vec{B}$. The number of lines in its Zeeman spectrum for transition from $n = 2, l = 1$ to $n = 1, l = 0$ is

[GATE 2024]

(a) 8 (b) 10 (c) 12 (d) 5

➢ JEST PYQ

1. The H_2 molecule has a reduced mass $M = 8.35 \times 10^{-28}$ kg and an equilibrium internuclear distance $R = 0.742 \times 10^{-10}$ m. The rotational energy in terms of the rotational quantum number J is :

[JEST 2016]

(a) $E_{\text{rot}}(J) = 7.J(J-1)\text{meV}$
(b) $E_{\text{rot}}(J) = \frac{5}{2}J(J+1)\text{meV}$
(c) $E_{\text{rot}}(J) = 7J(J+1)\text{meV}$
(d) $E_{\text{rot}}(J) = \frac{5}{2}J(J-1)\text{meV}$

➢ TIFR PYQ

1. Two homonuclear diatomic molecules produce different rotational spectra, even through the atoms are known to have identical chemical properties. This leads to the conclusion that the atoms must be

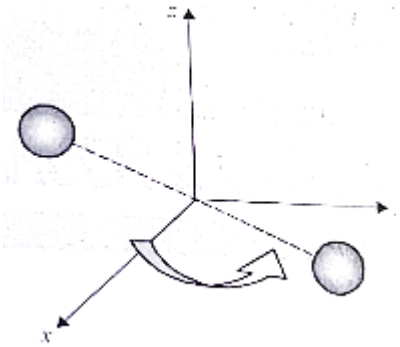
[TIFR 2016]

(a) isotopes, i.e. with the same atomic number
(b) isobars, i.e. with the same atomic weight
(c) isotones, i.e. with the same neutron number
(d) isomers, i.e. with the same atomic number and weight

2. The separation between neighboring absorption lines in a pure rotational spectrum of the hydrogen bromide (HBr) molecule is 2.23meV. If this molecule is considered as a rigid rotor and the atomic mass number of Br is 80 , the corresponding absorption line separation in deuterium bromide (DBr) molecule, in units of meV, would be **[TIFR 2017]**

(a) 2.234 (b) 1.115
(c) 1.128 (d) 4.461

3. Consider a diatomic molecule of oxygen which is rotating in the xy-plane about the z-axis. The z-axis passes through the centre of the molecule and is perpendicular to its length. At room temperature, the average separation between the two oxygen atoms is 1.21×10^{-10} m (the atoms are treated as point masses). The molar mass of oxygen is 16gm/mol. **[TIFR 2021]**



If the angular velocity of the molecule about the z-axis is 2×10^{12}rad/s, its rotational kinetic

energy will be closest to
(a) 7.78×10^{-22} Joule
(b) 15.56×10^{-22} Joule
(c) 1.95×10^{-22} Joule
(d) 3.89×10^{-22} Joule

4. Treat the hydrogen molecule H_2 as a rigid rotator. The next-to-largest wavelength in its rotational spectrum is about 111μm. From this it can be estimated that the separation between the pair of hydrogen atoms is about

[TIFR 2022]

(a) 0.12 nm (b) 24.4 nm
(c) 64.4 nm (d) 3.07μm

➢ OTHER EXAM PYQ

1. The $J = 0 \rightarrow J = 1$ transition line occurs at a frequency of 1.153×10^{11} s^{-1} in $^{12}C^{16}O$ and at a frequency of 1.102×10^{11} s^{-1} in $^{7}C^{16}O$. The mass number of the unknown isotope of carbon is (Given: The reduced mass of CO molecule is 1.14×10^{-26} kg)
(a) 13 (b) 14 (c) 15 (d) 16

Common Data for Q.2, Q. 3 and Q. 4
The separation of lines in the microwave red spectrum of HCl is 20.68 cm^{-1}. (Given: The reduced mass of HCl molecule is 1.62×10^{-27} kg)

2. The $J = 14 \rightarrow J = 15$ transition occurs at
(a) 103.4 cm^{-1} (b) 206.8 cm^{-1}
(c) 310.2 cm^{-1} (d) 413.6 cm^{-1}

3. The moment of inertia of the HCl molecule is
(a) 1.34×10^{-40} kg $-$ m^2
(b) 2.7×10^{-40} kg $-$ m^2
(c) 1.34×10^{-47} kg $- m^2$
(d) 2.7×10^{-47} kg $-$ m^2

4. The internuclear distance of HCl molecule is
(a) $0.48A^0$ (b) $0.84A^0$
(c) 1.30 A° (d) $1.95A^0$

5. The wave numbers (in cm^{-1}) of the lines of a band in the microwave region are given by
$\nu = 1000(2n-1)$ for positive ' n '
$= -1000(2n+1)$ for negative ' n '
The moment of inertia of the emitter molecule of the spectrum is
(a) 2.8×10^{-49} kg $-$ m^2
(b) 5.6×10^{-49} kg $-$ m^2
(c) 8.4×10^{-49} kg $- m^2$
(d) 11.2×10^{-49} kg $-$ m^2

6. Which one of the following molecule does not exhibit rotational spectra?
(a) CCl_4 (b) HF
(c) HBr (d) O_2

7. The lines in the microwave spectrum of $^{1}H^{127}I$ are separated by A cm^{-1}. The lines in the microwave spectrum of $^{2}H^{127}I$ will be separated by
(a) $\frac{A}{4}$ (b) $\frac{A}{2}$
(c) $\frac{A}{\sqrt{2}}$ (d) A

8. The spacing between the rotational lines of HF molecule is 40 cm^{-1}. The corresponding spacing between rotational lines in DF molecule is approximately
(a) 20 cm^{-1} (b) 30 cm^{-1}
(c) 60 cm^{-1} (d) 7.5 cm^{-1}

9. At a given temperature, for a rigid rotator, the probability that the system is in the rotational state J $= 0$ is 0.6 , in state J $= 1$ is 0.3 and in state J $= 2$ is 0.1 . The average enegy of the rotator at the given tempararture will be (Given: Rotational constant of the rotator is B)
(a) 6B (b) 1.2 B
(c) 3.6 B (d) 4.8 B

10. Consider the CO molecule as a diatomic rigid rotor with a bond length of 1.12Å. The reduced mass of the system is obtained from the atomic masses of C and O. The rotational energies are defined in terms of B (the rotational constant) and J (the rotational quantum number). If ν_1 and ν_2 denotes the frequency of the first rotational resonance lines for the moleules $^{12}C^{16}O$ and $^{13}C^{18}O$ respectively, their ratio ν_1/ν_2 is approximately.
(a) 1.5 (b) 1.1 (c) 0.9 (d) 1.01

11. In which of the following pairs do both molecules exhibit rotational spectra?
(a) CCl_4 and HF (b) CCl_4 and O_2
(c) HCN and HF (d) HCN and CCl_4

12. The population in the first rotational state of diatomic molecule relative to the lowest state is

$3e^2$. The relative population in the second rotational state is
(a) $4e^{-3}$ (b) $5e^{-4}$
(c) $5e^{-6}$ (d) $4e^{-5}$

13. The relative population in two states with energies E_1 and E_2 satisfying Boltzmann distribution is given by

$$\frac{n_1}{n_2} = \frac{3}{2}\exp\left[-\frac{(E_2 - E_1)}{k_B T}\right]$$

The relative degeneracy g_2/g_1 is
(a) 2 (b) 2/3 (c) 3/2 (d) 3

14. The equilibrium population ratio (n_f/n_t) of a doubly degenarate level (E_f) lying at energy 2 units higher than a lower non-degenarate energy level (E_i), will be (assuming $k_B T = 1$ unit)
(a) $\frac{2}{e^2}$ (b) $\frac{1}{e^2}$
(c) e^2 (d) $2e^2$

15. The population of Jth rotational level is given by

$$N_J = N_0(2J+1)\exp\left[-\frac{BJ(J+1)}{k_B T}\right]$$

where N_0 is the population in the ground state. The J value of the rotational level with maximum population is given by,
(a) $\frac{\left[\frac{2kT}{B}-1\right]}{\sqrt{2}}$ (b) $\frac{\left[\frac{2kT}{B}--1\right]}{\sqrt{2}}$
(c) $\frac{kT}{B}$ (d) $\frac{B}{kT}$

16. Three consecutive lines in the microwave spectrum of HBr molecule are found to be at 84.544 cm^{-1}, 101.355 cm^{-1} and 118.112 cm^{-1} respectively. The rotational constant of the HBr molecule is
(a) 3.7 cm^{-1} (b) 5.2 cm^{-1}
(c) 6.9 cm^{-1} (d) 8.5 cm^{-1}

17. The strongest three lines in the emission of an interstellar gas cloud are found to have wavelengths λ_0, $2\lambda_0$ and $6\lambda_0$ respectively, where λ_0 is a known wavelength. From this we can deduce that he radiating particles in the cloud behave like
(a) free particles
(b) Particles in a box
(c) Harmonic oscillators
(d) Rigid rotators

18. Typical energy of the rotational modes in a polyatomic molecule like NH_3 is:
(a) 10^{-6}eV (b) 10^{-3}eV
(c) 10^{-4}eV (d) 1Ev

19. Which one of the following molecules does not exhibit a rotational spectrum?
(a) H_2 (b) CO
(c) HCl (d) HBr

20. The molecular spectra of two linear molecules O-C-O and O-C-S are recorded in the microwave region, Which one of the following statement is correct?
(a) Both the molecules would show absorption lines
(b) Both the molecules would not show absorption lines
(c) O-C-O would show absorption lines, but not O-C-S.
(d) O-C-S would show absorption lines, but not O-C-O.

21. The rotational energy levels of a rigid diatomic molecules are given by $E_J = B_e J(J+1)$ where J is the rotational quantum number and B_e is the constant. The rotational absorption spectrum of the molecules therefore consists of
(a) One resonance line
(b) Lines that are equally spaced.
(c) Lines where the spacing increases with frequency
(d) Lines where the spacing decreases with frequency.

22. The sharpest spectrum lines in the microwave rotational spectrum are observed when the sample is a
(a) solid (b) liquid
(c) liquid crystal (d) gas

23. Which one of the following molecules does not exhibit a rotational spectrum?
(a) H_2 (b) CO (c) HCl (d) HBr

24. The pure rotational levels of a molecule in the far-infrared region follows the formula $F(J) = BJ(J+1)$, where $F(J)$ is the energy of the rotational level with quantum number J and B is the rotational constant. The lowest rotational energy gap in rotational Raman spectrum is :
(a) 2 B (b) 4 B (c) 6 B (d) 8 B

25. You are shown a spectrum consisting of a series of equally spaced lines. This could be
(a) The rotational spectrum CO.
(b) The vibrational spectrum of N_2.
(c) The NMR spectrum of CH_4
(d) The Mossbauer spectrum of Fe_3O_4.

26. The absorption lines arising from pure rotational effects of HCl are observed at 83.03 cm^{-1}, 103.73 cm^{-1}, 124.30 cm^{-1}, 145.03 cm^{-1} and 165.51 cm^{-1}. The moment of inertia of the HCl molecule is (take $\frac{\hbar}{2\pi c} = 5.6 \times 10^{-44}$ kg − m)

(a) 1.1×10^{-48} kg − m^2
(b) 2.8×10^{-47} kg − m^2
(c) 2.8×10^{-48} kg − m^2
(d) 1.1×10^{-42} kg − m^2

27. The spin-orbit interaction in a hydrogen-like atom is given by the Hamiltonian

$$H' = -k\vec{L} \cdot \vec{S}$$

where k is a real constant. The splitting between levels $^2p_{3/2}$ and $^2p_{1/2}$ due to this interaction is

(a) $\frac{1}{2}k\hbar^2$ (b) $\frac{3}{2}k\hbar^2$
(c) $\frac{3}{4}k\hbar^2$ (d) $2k\hbar^2$

28. Atomic numbers of V, Cr, Fe and Zn are 23,24, 26 and 30, respectively. Which one of the following materials does NOT show an electron spin resonance (ESR) spectra?

(a) V (b) Cr
(c) Fe (d) Zn

29. The mean distance between the two atoms of HD molecule is r, where H and D denote hydrogen and deuterium, respectively. The mass of the hydrogen atom is m_H. The energy difference between two lowest lying rotational states of HD in multiples of $\hbar^2/(m_H r^2)$ is

(a) $\frac{3}{2}$ (b) $\frac{2}{3}$ (c) 6 (d) $\frac{4}{3}$

30. Which one of the following options is the most appropriate match between the items given in Column 1 and Column 2?

Column 1	Column 2
(i) Visible light	P. Transition between core energy levels of atoms
(ii) X-rays	Q. Transition between nuclear energy levels
(iii) Gamma rays	R. Pair production
(iv) Thermal neutrons	S. Crystal structure determination
	T. Photoelectric effect

(a) (i) - T; (ii) - P, S, T; (iii) - Q, R; (iv) - S
(b) (i) - P, T; (ii) - S; (iii) - R, S; (iv) - S, T
(c) (i) - T; (ii) - R, S; (iii) - Q, R; (iv) - S
(d) (i) - S, T; (ii) - P, S; (iii) - R, T; (iv) - S

31. An excited state of Ca atom is [Mg]$3p^5 4\,s^2 3\,d^1$. The spectroscopic terms corresponding to the total orbital angular momentum are

(a) S, P, and D (b) P, D, and F
(c) P and D (d) S and P

32. For normal Zeeman lines observed ∥ and ⊥ to the magnetic field applied to an atom, which of the following statements are true?

(a) Only π-lines are observed || to the field
(b) σ-lines ⊥ to the field are plane polarized
(c) π-lines ⊥ to the field are plane polarized
(d) Only σ-lines are observed I| to the field

33. A gas of atoms, each of mass m, in thermal equilibrium at a temperature T, is radiating with a frequency v_0. The Doppler broadening (full width at half maximum, or FWHM) of the observed spectral line would be given by

(a) $\frac{2v_0}{c}\sqrt{\frac{2\ln 2k_bT}{m}}$ (b) $\frac{v_0}{c}\sqrt{\frac{2k_BT}{m}}$
(c) $\frac{2v_0}{c}\sqrt{\frac{\ln 2k_BT}{m}}$ (d) $\frac{2v_0}{c}\sqrt{\frac{2k_BT}{m}}$

34. In a semiclassical approach, the Hamiltonian of a He atom is modified by adding a magnetic interaction term between the two electrons, of the form

$$H_1 = A_2\vec{S}_1 \cdot \vec{S}_2$$

Where $\vec{S}_1$ and $\vec{S}_2$ are the electron spins and A_2 is a coupling constant. This leads, for the configuration $1s^2$, to the energy shift

(a) $-3A_2/4$ (b) $+3A_2/4$
(c) $+A_2/4$ (d) $-3A_2/4$

❖ Answer Key

NET-PYQ				
1-c	2-b	3-b	4-b	

GATE PYQ				
1. b	2.	3.	4. b	5. b
6. c	7. d	8. a	9. b	10. a
11. a	12. b	13. b	14. 10	15. a
16. a				

Q2 1.959,1.891cm^{-1} ,25744 cm^{-1}

JEST PYQ
1-c

TIFR PYQ			
1-a	2-c	3-d	4-a

OTHER EXAM PYQ				
1-a	2-c	3-d	4-c	5-a
6-a,d	7-b	8-a	9-b	10-b
11-c	12-c	13-b	14-a	15-b
16-d	17-d	18-c	19-a	20-d
21-b	22-a	23-a	24-c	25-a
26-b	27-b	28-d	29-a	30-a
31-b	32-b,c,d	33-a	34-a	

❖ AMP Assignment:

➢ **Vibrational spectroscopy and Rotational-vibrational spectroscopy**

➢ **CSIR-NET PYQ's**

1. If the leading anharmonic correction to the energy of the n-th vibrational level of a diatomic molecule is $-x_e\left(n+\frac{1}{2}\right)^2\hbar\omega$ with $x_e = 0.001$, the total number of energy levels possible is approximately

[NET Dec. 2014]

(a) 500 (b) 1000
(c) 250 (d) 750

2. A diatomic molecule has vibrational states with energies $E_v = \hbar\omega\left(v+\frac{1}{2}\right)$ and rotational states with energies $E_j = Bj(j+1)$, where v and j are non-negative integers. Consider the transitions in which both the initial and final states are restricted to $v \leq 1$ and $j \leq 2$ and subject to the selection rules $\Delta v = \pm 1$ and $\Delta j = \pm 1$. Then the largest allowed energy of transition is

[NET June 2015]

(a) $h\omega - 3B$ (b) $\hbar\omega - B$
(c) $h\omega + 4B$ (d) $2\hbar\omega + B$

3. The first ionization potential of K is 4.34eV, the electron affinity of Cl is 3.82eV and the equilibrium separation of KCl is 0.3 nm. The energy required to dissociate a KCl molecule into a K and a Cl atom is

[CSIR-DEC 2015]

(a) 8.62eV (b) 8.16eV
(c) 4.28eV (d) 4.14eV

4. In the rotational-vibrational spectrum of an idealized carbon monoxide (CO) molecule, ignoring rotational-vibrational coupling, two transitions between adjacent vibrational levels with wavelength λ_1 and λ_2, correspond to the rotational transition from $J' = 0$ to $J'' = 1$, and $J' = 1$ to $J'' = 0$, respectively. Given that the reduced mass of CO is $1.2 \times^{-26}$ kg, equilibrium bond length of CO is 0.12 nm and vibrational frequency is 5×10^{13} Hz, the ratio of $\frac{\lambda_1}{\lambda_2}$ is closest to **[CSIR-DEC 2023]**

(a) 0.9963 (b)0.0963
(c)1.002 (d)1.203

5. The bond dissociation energy of a molecule is defined as the energy required to dissociate it. For H_2 and H_2^+ molecules, the bond dissociation energies are 4.478 eV and 2.651 eV respectively. If the equilibrium bond lengths of both H_2 and H_2^+ are identical, the value of the ionization potential of hydrogen molecule will be closest to **[CSIR-JUNE 2024]**

(a) 15.427eV (b) 11.773eV
(c) 20.729eV (d)6.471 eV

➢ **GATE PYQ**

1. For a diatomic molecule with the vibrational quantum number n and rotational quantum number J, the vibrational level spacing $\Delta E_n = E_n - E_{n-1}$ and the rotational level spacing $\Delta E_j = E_j - E_{j-1}$ are approximately **[GATE 2005]**

(a) ΔE_n = constan t, ΔE_j = constan t
(b) ΔE_n = constan t, $\Delta E_J \propto J$
(c) $\Delta E_n \propto n, \Delta E_J \propto J$
(d) $\Delta E_n \propto n, \Delta E_j \propto J^2$

2. A vibrational electronic spectrum of homonuclear binary molecules, involving electronic ground state ε'' and excited ε', exhibits a continuum at $\bar{\nu}\,\text{cm}^{-1}$. If the total energy of the dissociated atoms in the excited state exceeds the total energy of the dissociated atoms in the ground state by $E_{ex}\,\text{cm}^{-1}$, then dissociation energy of the molecule in the ground state is

[GATE 2006]

(a) $\frac{(\bar{\nu}+E_{ex})}{2}$ (b) $\frac{(\bar{\nu}-E_{ex})}{2}$

(c) $(\bar{\nu}-E_{ex})$ (d) $\sqrt{(\bar{\nu}^2-E_{ex}^2)}$

3. Which one of the following statement is INCORRECT in vibrational spectroscopy with anharmonicity? **[GATE 2008]**

(a) The selection rule for vibrational spectroscopy is $\Delta v = \pm 1, \pm 2, \ldots.$

(b) Anharmonicity leads to multiple absorption lines

(c) The intensities of hot band lines are stronger than the fundamental absorption.

(d) The frequencies of hot band lines are smaller than the fundamental absorption.

4. The molecular spectra of two linear molecules $O-C-O$ and $O-C-S$ are recorded in the microwave region. Which one of the following statement is correct?

[GATE 2008]

(a) both the molecules would show absorption lines

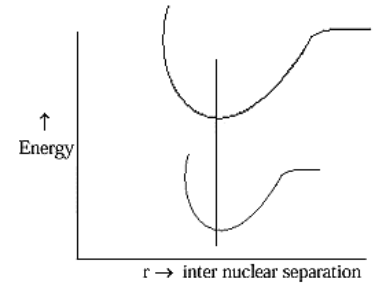
(b) both the molecules would not show absorption lines

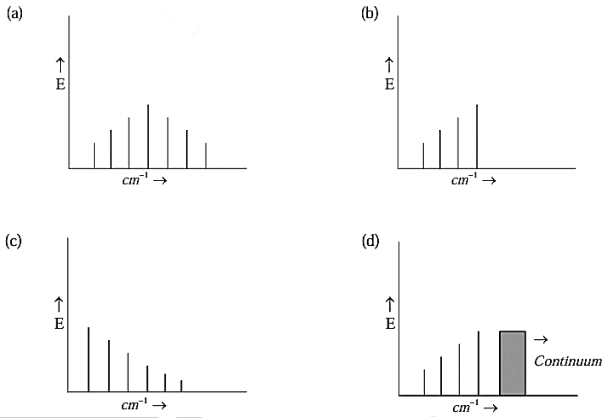
(c) $O-C-O$ would show absorption lines, but not $O-C-S$

(d) O-C-S would show absorption lines, but not $O-C-O$

5. In a diatomic molecule, the internuclear separation of the ground and first excited electronic state are the same as shown in the figure. If the molecule is initially in the lowest vibrational state of the ground state, then the absorption spectrum will appear as

[GATE 2009]





a

6. Match the typical spectroscopic regions specified in Group I with the corresponding type of transitions in Group II.

[GATE 2012]

Group I

(P) Infra-red region

(Q) Ultraviolet-visible region

(R) X-ray region

(S) γ-ray region

Group II

(i) electronic transitions involving valence electrons

(ii) nuclear transitions

(iii) vibrational transitions of molecules

(iv) transitions involving inner shell electrons

(a) (P, i), (Q, iii), (R, ii), (S, iv)

(b) (P, ii), (Q, iv), (R, i), (S, iii)

(c) (P, iii), (Q, i), (R, iv), (S, ii)

(d) (P, iv), (Q, i), (R, ii), (S, iii)

7. The equilibrium vibration frequency for an oscillator is observed at 2990 cm^{-1}. The ratio of the frequencies corresponding to the first and the fundamental spectral lines is 1.96. Considering the oscillator to be anharmonic, the anharmonicity constant is

[GATE 2012]

(a) 0.005 (b) 0.02

(c) 0.05 (d) 0.1

8. The spacing between vibrational energy levels in CO molecule is found to be 8.44×10^{-2}eV. Given that the reduced mass of CO is 1.14×10^{-26} kg, Planck's constant is 6.626×10^{-34} J and $1\text{eV} = 1.6 \times 10^{-19}$ J. The force constant of the bond in CO molecule is

[GATE 2013]

(a) 1.87 N/m (b) 18.7 N/m
(c) 187 N/m (d) 1870 N/m

9. The expression for the second overtone frequency in the vibrational absorption spectra of a diatomic molecules in terms of the harmonic frequency ω_e and anharmonicity constant x_e is

[GATE 2018]

(a) $2\omega_e(1 - x_e)$ (b) $2\omega_e(1 - 3x_e)$
(c) $3\omega_e(1 - 2x_e)$ (d) $3\omega_e(1 - 4x_e)$

10. Consider a diatomic molecule formed by identical atoms. If E_V and E_e represent the energy of the vibrational nuclear motion and electronic motion respectively, then in terms of the electronic mass m and nuclear mass M, E_V/E_e is proportional to

[GATE 2020]

(a) $(m/M)^2$ (b) $(m/M)^{1/2}$
(c) m/M (d) $(m/M)^{3/2}$

11. The spacing between two consecutive S-branch lines of the rotational Raman spectra of hydrogen gas is 243.2 cm^{-1}. After excitation with a laser of wavelength 514.5 nm, the Stoke's line appeared at 17611.4 cm^{-1} for a particular energy level. The wavenumber (rounded off to the nearest integer), in cm^{-1}, at which Stoke's line will appear for the next higher energy level is 17360.2

[GATE 2021]

➢ TIFR PYQ

1. The minimum energy required to dissociate a hydrogen molecule H_2 into two atoms is 4.5eV. If the electron affinity of the hydrogen atom is 0.75eV, the minimum energy required to dissociate the hydrogen molecule into $H^+$and H^-would be

[TIFR 2023]

(a) 17.35Ev (b) 14.35eV
(c) 18.85eV (d) 5.25eV

➢ OTHER EXAM PYQ

1. Which of the following molecules has the lowest vibrational frequency?

(a) $^4H^{35}Cl$ (b) $^2H^{35}Cl$
(c) $^4H^{36}Cl$ (d) $^4H^{37}Cl$

Linked Answer Type Q. 2 and Q. 3
The IR spectrum of a diatomic molecule exhibits transitions at $2144\ \text{cm}^{-1}, 4262\ \text{cm}^{-1}, 6354\ \text{cm}^{-1}$ corresponding to the excitations from the ground state to the first, second, third vibration states respectively.

2. The vibrational constants (in cm^{-1}) of the diatomic molecule is at

(a) 2157 (b) 2170
(c) 2183 (d) 2196

3. The anharmonicity constant (in cm^{-1}) of the diatomic molecule is

(a) 0.018 (b) 0.012
(c) 0.006 (d) 0.003

4. The vibrational energy levels $v'' = 0$ and $v = 1$ of a diatomic molecule are separated by 2143 cm^{-1}. It's anharmonicity $(\omega_e x_e)$ is 14 cm^{-1}. The values of ω_e (in cm^{-1}) and first vertone (in cm^{-1}) of this molecule are respectively

(a) 2143,4286 (b) 2157,4286
(c) 2157,4314 (d) 2171,4258

5. The Infrared spectrum of HCl gas shows an absorption band centered at 2885 cm^{-1}. The zero point energy of HCl molecule under harmonics oscillator approximation is

(a) 2.8865×10^{-22} J (b) 2.8865×10^{-20} J
(c) 5.7730×10^{-20} J (d) 5.7730×10^{-22} J

6. Overtones are observed in the vibrational spectra of diatomic molecules when

(a) Anharmonicity is large
(b) Anharmonicity is absent
(c) Vibrational and rotational modes are coupled
(d) An alternating electric field is applied

Common Data for Q. 7 and Q. 8
The fundamental band and the first overtone for CO molecule is centered at 2143.3 cm^{-1} and 4259.7 cm ^{1} respectively. (Given: The reduced mass of CO molecule is 1.14×10^{-26} kg)

7. The vibrational frequency of CO molecule is

(a) 2170 cm^{-1} (b) 2467 cm^{-1}
(c) 1108 cm^{-1} (d) 3456 cm^{-1}

8. The value of ω_x of CO molecule will be
(a) 6.8 cm^{-1} (b) 10.2 cm^{-1}
(c) 13.5 cm^{-1} (d) 19.5 cm^{-1}

9. The ratio between the fundamental vibrational frequencies of HI and DI is
(a) $\frac{1}{2}$ (b) 2 (c) $\frac{1}{\sqrt{2}}$ (d) $\sqrt{2}$

10. Replacement of hydrogen by deuterium atom bound to a heavy atom X in a polyatomic molecule would reduce the vibrational frequency of X – H streching by a factor of
(a) 2 (b) $\sqrt{2}$ (c) 4 (d) 1.3

11. The R branch in the vibrational spectra of AX molecule exhibits a set equally spaced lines with a separation of 10 cm^{-1}. The rotational constant of AX molecule is
(a) 10 cm^{-1} (b) 20 cm^{-1}
(c) 5 cm^{-1} (d) 15 cm^{-1}

12. The vibrational-rotational energy of a diatomic molecule may be written as (where v is the frequency of vibration and I is the moment of inertia of the molecule)
(a) $\left(n+\frac{1}{2}\right)hv+\frac{h^2}{2I}J(J+1)$ [$n = 1,2,3$ ….
. and $J = 0,1,2,3$ …]
(b) $\left(n+\frac{1}{2}\right)hv+\frac{h^2}{2I}J(J+1)$ [$n = 0,1,2,3$ ….
. and $J = 0,1,2,3$ ….
(c) $\left(n+\frac{1}{2}\right)hv+\frac{h^2}{2I}M^2$ [$n = 1,2,3$ ….
. and $M = 0,\pm1,\pm2,\pm3$ ….
(d) $\left(n+\frac{1}{2}\right)hv+\frac{h^2}{2I}M^2$ [$n = 0,1,2,3$ ….
. and $M = 0,1,2,3$ ….

13. The selection rules for the appearances of P branch in the rotational vibrational absorption spectra of a diatomic molecule with rigid rotator-harmonic oscillator model are
(a) $\Delta v = \pm1, \Delta J = \pm1$
(b) $\Delta v = +1, \Delta J = +1$
(c) $\Delta v = +1, \Delta J = -1$
(d) $\Delta v = -1, \Delta I = -1$

14. The rotational constant for CO molecule in the ground state and the first excited states are 1.9 cm^1 and 1.6 cm^{-1} respectively. The percentage change in the internuclear distance due to vibrational excitation is
(a) 9 (b) 30 (c) 16 (d) 0

15. In the IR spectrum of $[Co(CN)_5H]^{3-}$ the $Co-H$ strech is observed at 1840 cm^{-1}. The $Co-D$ strech in $[Co(CN)_5D]^{3-}$ will appear at nearly
(a) 1300 cm^{-1} (b) 1400 cm^{-1}
(c) 1500 cm^{-1} (d) 1600 cm^{-1}

16. The fundamental mode of HCl occurs at 2886 cm^{-1}. The fundamental mode of DCl will occur
(a) 1367 cm^{-1} (b) 2069 cm^{-1}
(c) 2778 cm^{-1} (d) 3024 cm^{-1}

17. The moment of inertia of the HCl^{35} molecule in the $v = 0$ and $v = 1$ levels is 20.8×10^{-7} kg – m^2.
The wave number difference between the $R(0)$ and $P(1)$ lines of the fundamemtal band for HCl^{35} molecule is
(a) 4164 m^{-1} (b) 1041 m^1
(c) $2082m'$ (d) 5205 m^{-1}

18. There is no infrared absorption for nitrogen molecule because:
(a) Its polarizability is zero
(b)It has no vibrational levels
(c) It has no rotational levels
(d) Its dipole moment is zero

19. Infrared absorption can be observed in which of the following molecules?
(a) N_2 (b) O_2 (c) HCl (d) C_2

20. All vibrations producing a change in the electric dipole moment of a molecule yield
(a) Raman spectra (b) Infrared spectra
(c) Ultra-violet spectra (d) X-ray spectra

21. The typical wavelengths emitted by diatomic molecules in purely vibrational and purely rotational transitions are respectively in the region of
(a) Infrared and visible
(b) Visible and infrared
(c) Infrared and microwave
(d) Microwave and infrared

22. Which of the diatomic molecules H_2, HD, D_2 and HT has the highest vibrational frequency?
(a) HT (b) D_2 (c) HD (d) H_2

23. The spacing between vibrational energy levels in CO molecule is found to be 8.441×10^{-2}eV. Given that the reduced mass of CO is 1.14×10^{-26} kg, Planck's constant is 6.626×10^{-34}Js and $1\text{eV} = 1.6 \times 10^{-19}$ J. The force constant of the bond is CO molecule is

(a) 1.87 N/m (b) 18.7 N/m
(c) 187 N/m (d) 1870 N/m

24. Infrared absorption can be observed in which of the following molecules?

(a) N_2 (b) O_2 (c) HCl (d) C_2

25. All vibrations producing a change in the electric dipole moment of a molecule yield

(a) Raman spectra
(b) Infrared spectra
(c) Ultra-violet spectra
(d) X-ray spectra

26. The typical wavelengths emitted by diatomic molecules in purely vibrational and purely rotational transitions are respectively in the region of

(a) Infrared and visible
(b) Visible and infrared
(c) Infrared and microwave
(d) Microwave and infrared

27. The unequal spacing in the vibrational energy levels of a diatomic molecule would be due to the

(a) Presence of anharmonic terms in the potential energy,
(b) Finite mass of the nuclei.
(c) Frank-Condon principle,
(d) Harmonic nature of the potential energy,

28. In the rotational-vibrational spectrum of an idealized carbon monoxide (CO) molecule, ignoring rotational-vibrational coupling, two transitions between adjacent vibrational levels with wavelength λ_1 and λ_2, correspond to the rotational transition from $J' = 0$ to $J'' = 1$, and $J' = 1$ to $J'' = 0$, respectively. Given that the reduced mass of CO is $1.2x^{-26}$ kg, equilibrium bond length of CO is 0.12 nm and vibrational frequency is 5×10^{13} Hz, the ratio of $\frac{\lambda_1}{\lambda_2}$ is closest to

(a) 0.9963 (b) 0.0963
(c) 1.002 (d) 1.203

29. The ionization potential of hydrogen atom is 13.6eV, and λ_H and λ_D denote longest wavelengths in Balmer spectrum of hydrogen and deuterium atoms, respectively. Ignoring the fine and hyperfine structures, the percentage difference $y = \frac{\lambda_H - \lambda_D}{\lambda_H} \times 100$, is closest to

(a) 1.0003% (b) -0.03%
(c) 0.03% (d) -1.0003%

30. Two electrons in thermal equilibrium at temperature $T = \frac{k_B}{\beta}$ can occupy two sites. The energy of the configuration in which they occupy the different sites is JS_1S_2 (where J>0is a constant and S denotes the spin of an electron), while it is U if they are at the same site. If $U = 10$ J, the probability for the system to be in the first excited state is

[June 2023]

(a) $e^{-3\beta J/4}/\left(3e^{\beta J/4} + e^{-3\beta J/4} + 2e^{-10\beta}\right)$
(b) $3e^{-\beta J/4}/\left(3e^{-\beta/4} + e^{3\beta J/4} + 2e^{-10\beta J}\right)$
(c) $e^{-\beta J/4}/\left(2e^{-\beta J/4} + 3e^{3\beta/4} + 2e^{-10\beta}\right)$
(d) $3e^{-3\beta J/4}/\left(2e^{\beta J/4} + 3e^{-3\beta J/4} + 2e^{-10\beta J}\right)$

31. In a diatomic molecule of mass M, electronic, rotational and vibrational energy scales are of magnitude E_e, E_R and E_V, respectively. The spring constant for the vibrational energy is determined by E_e. If the electron mass is m then

(a) $E_R \sim \frac{m}{M} E_e$ (b) $E_R \sim \sqrt{\frac{m}{M}} E_e$
(c) $E_V \sim \sqrt{\frac{m}{M}} E_e$ (d) $E_V \sim \left(\frac{m}{M}\right)^{1/4} E_e$

32. The number of hyperfine states found in the He^3 atom for the electronic configuration $1s^1 2s^0 2p^1$ would be

(a) 7 (b) 2 (c) 4 (d) 1

33. The energy gap between the $n = 1$ and the $n = 2$ energy levels of a hydrogen atom is denoted E_0.Now, consider a muonic carbon ion C^{5+}, i.e., a carbon nucleus (${}_6C^{12}$) orbited by a muon $\mu\left(q = -e, M_p = 210m_e\right)$. The energy of the photon emitted in the transition of the muon from the $n = 3$ level to the $n = 2$ level of this ion will be approximately

(a) $1400E_0$ (b) $235E_0$
(c) $1050E_0$ (d) $7560E_0$

❖ Answer Key

NET-PYQ				
1. **c**	2. c	3. c	4. a	5. a

GATE PYQ				
1. b	2. c	3. b	4. d	5. a
6. c	7. b	8. c	9. d	10. b
11. 17360.2				

TIFR PYQ
1. a

OTHER EXAM PYQ				
1-d	2-b	3-c	4-d	5-b
6-a	7-a	8-c	9-d	10-d
11-b,c	12-b	13-c	14-a	15-a
16-b	17-d	18-d	19-c	20-b
21-c	22-d	23-c	24-c	25-b
26-c	27-c	28-c	29-c	30-b
31-a,c	32-a	33-a		

❖ AMP Assignment: (Raman Spectra)

1. A laser operating at 500 nm is used to excite a molecule. If the Raman shift is observed at 770 cm^{-1}, the approximate positions of the ani-Stokes and the Stokes lines are

[NET Dec. 2011]

(a) 481.5 nm and 520 nm
(b) 481.5 nm and 500 nm
(c) 500 nm and 520 nm
(d) 500 nm and 600 nm

2. The energy levels corresponding to the rotational motion of a molecule are $E_J = BJ(J+1)cm^{-1}$ where $J = 0,1,2,\ldots..$ and B is a constant. Pure rotational Raman transitions follow the selection rule $\Delta J = 0, \pm 2$. When the molecule is irradiated, the separation between the closest stokes and anti-Stokes lines (in cm^{-1}) is

[NET June 2019]

(a) $6B$ (b) 12 B (c) $4B$ (d) $8B$

3. In a spectrum resulting from Raman scattering, let I_R denote the intensity of Rayleigh scattering and I_S and I_{AS} denote the most intense Stokes line and the most intense anti-Stokes line, respectively. The correct order of these intensities is

[CSIR-DEC 2019]

(a) $I_S > I_R > I_{AS}$ (b) $I_R > I_S > I_{AS}$
(c) $I_{AS} > I_R > I_S$ (d) $I_R > I_{AS} > I_S$

4. The Raman rotational-vibrational spectrum of nitrogen molecules is observed using an incident radiation of wavenumber 12500 cm^{-1}. In the first shifted band, the wavenumbers of the observed lines (in cm^{-1}) are 10150,10158,10170,10182 and 10190. The values of vibrational frequency and rotational constant (in cm^{-1}), respectively, are`

[NET June 2022]

(a) 2330 and 2 (b) 2350 and 2
(c) 2350 and 3 (a) 2330 and 3

5. Let the separation of the frequencies of the first Stokes and the first anti-Stokes lines in the pure rotational Raman Spectrum of the H_2 molecule be $\Delta v(H_2)$ while the corresponding quantity for D_2 is $\Delta v(D_2)$. The ratio $\frac{\Delta v(H_2)}{\Delta v(D_2)}$ is

[CSIR-JUNE 2023]

(a) 0.6 (b) 1.2 (c) 1 (d) 2

➢ GATE PYQ

1. Light of wavelength 1.5μm incident on a material with a characteristic Raman frquency of 20×10^{12} Hz results in a stokes-shifted line of wavelength [Given : $c = 3 \times 10^8$ m $\cdot$ s^{-1}]

[GATE 2002]

(a) 1.47μm (b) 1.57μm
(c) 1.67μm (d) 1.77μm

2. Consider the following statements about molecular spectra
P CH_4 does not give pure rotational Raman lines
Q SF_6 could be studied by rotational Raman spectroscopy
R N_2 shows infrared absorption spectrum
S CH_3CH_3 shows vibrational Raman and infrared absorption lines
T H_2O_2 shows pure rotational spectrum
Choose the right combination of correct statements

[GATE 2003]

(a) P and Q (b) P, R and T
(c) P, S and T (d) Q and R

3. Light of wavelength 1.5μm incident on a material with a characteristic Raman frequency of 20×10^{12} Hz results in a Stokes-shifted line of wavelength
[Given: $c = 3 \times 10^8$ m $\cdot$ s^{-1}]

[GATE 2004]

(a) 1.47μm (b) 1.57μm
(c) 1.67μm (d) 1.77μm

4. In the Raman scattering experiment, light of frequency v from a laser is scatteered by diatomic molecules having moment of inertia I. The typical Raman shifted frequency depends on

[GATE 2005]

(a) v and I (b) only v
(c) only I (d) neither v nor I

5. Match the following and choose the correct combination

[GATE 2005]

Group-I`
P. Atomic configuration $1s^2 2s^2 2p^6 3s^2 3p^6$
Q. Strongly electropositive
R. Strongly electronegative
S. Covalent bonding
Group-2
1. Na
2. Si
3. Ar
4. Cl

(a) P-1, Q-2, R-3, S-4 (b) P-3, Q-2, R-4, S-1
(c) P-3, Q-1, R-4, S-2 (d) P-3, Q-4, R-1, S-2

6. A vibrational-electronic spectrum of homonuclear binary molecules, involving electronic ground state ε'' and excited ε', exhibits a continuum at $\bar{\nu}$ cm^{-1}. If the total energy of the dissociated atoms in the excited state exceeds the total energy of the dissociated atoms in the ground state by E_{ex}cm^{-1}, then dissociation energy of the molecule in the ground state is :

[GATE 2006]

(a) $(\bar{\nu} + E_{ex})/2$ (b) $(\bar{\nu} - E_{ex})/2$
(c) $(\bar{\nu} - E_{ex})$ (d) $\sqrt{(\bar{\nu}^2 - E_{ex}{}^2)}$

7. Match the following:

[GATE 2007]

P: Franck-Hertz experiment
1.Electronic excitation of molecules Wave function of atom
Q: Hartree-Fock method 2.
R: Stern-Gerlach experiment
3. Spin angular momentum of atoms
S: Franck-Condon principle
4. Energy levels in atoms

(a)	(b)	(c)	(d)
P-4	P-1	P-3	P-4
Q-2	Q-4	Q-2	Q-1
R-3	R-3	R-4	R-3
S-1	S-2	S-1	S-2

8. The number of fundamental vibrational modes of CO_2 molecule is

[GATE 2007]

(a) four: 2 are Raman active and 2 are infrared active
(b) four: 1 is Raman active and 3 are infrared active
(c) three: 1 is Raman active and 2 are infrared active
(d) three: 2 are Raman active and 1 is infrared active

9. A pure rotational Raman spectrum of a linear diatomic molecule is recorded using electromagnetic radiation of frequency v_e. The frequency of two consecutive stokes lines are :

[GATE 2008]

(a) $\nu_e - 10$ B, $\nu_e - 14$ B (b) $\nu_e - 2$ B, $\nu_e - 4$ B
(c) $\nu_e + 10$ B, $\nu_e + 14$ B (d) $v_e + 2B, v_e + 4B$

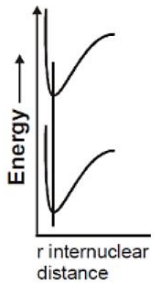
10. The separation between the first stokes and corresponding anti-stokes lines of the rotational Raman spectrum in terms of the rotational constant, B is : .

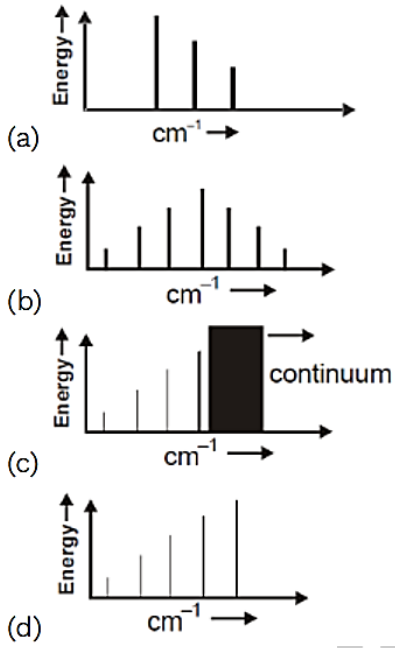
[GATE 2009]

(a) 2 B (b) 4 B (c) 6 B (d) 12 B

11. In a diatomic molecule, the internuclear separation of the ground and first excited electronic state are the same as shown in the figure. If the molecule is initially in the lowest vibrational state of the ground state, then the absorption spectrum will appear as

[GATE2009]





12. Match the typical spectra of stable molecules with the corresponding wave-number mage

[GATE 2010]

1.Electronic spectra i. 10^6 cm^{-1} and above
2. Rotational spectra ii. $10^5 - 10^6$ cm^{-1}
3. Molecular dissociation iii. $10^\circ - 10^2$ cm^{-1}

(a) 1-ii, 2-i, 3-iii
(b) 1-ii, 2-iii, 3-i
(c) 1-iii, 2-ii, 3-i
(d) $1 - i, 2 - ii, 3 - iii$.

13. The far infrared rotational absorption spectrum of diatomic molecule shows equidistant blines with spacing 20 cm^{-1}. The position of the first stokes line in the rotational Raman spectrum of the molecule is

[GATE 2011]

(a) 20 cm^{-1} (b) 40 cm^{-1}
(c) 60 cm^{-1} (d) 120 cm^{-1}

14. The first Stokes line of a rotational Raman spectrum is observed at 12.96 cm^{-1}. Considering rigid rotator approximation, the rotational constant is given by

[GATE 2012]

(a) 6.48 cm^{-1} (b) 3.24 cm^{-1}
(c) 2.16 cm^{-1} (d) 1.62 cm^{-1}

15. Match the typical spectroscopic regions specified in Group I With the corresponding type of transitions in Group II.

[GATE 2012]

Group I
(P) Infra-red region
(Q) Ultraviolet-visible region
(R) X-ray region
(S) γ-ray region

Group II
(i) electronic transitions involving valence electrons
(ii) nuclear transitions
(iii) vibrational transitions of molecules
(iv) transitions involving inner shell electrons
(a) (P, i); (Q, iii); (R, ii); (S, iv)
(b) (P, ii); (Q, iv); (R, i); (S, iii)
(c) (P, iii); (Q, i); (R, iv); (S, ii)
(d) (P, iv); (Q, i); (R, ii); (S, iii)

16. The excitation wavelength of laser in a Raman effect experiment is 546 nm. If the Stokes line is observed at 552 nm, then the wave number of the anti-Stokes line (in cm^{-1}) is .....

[GATE 2015]

17. The molecule $^{17}O_2$ is **[GATE 2016]**
(a) Raman active but not NMR (nuclear magnetic resonance) active
(b) Infrared active and Raman active but not NMR active
(c) Raman active and NMR active
(d) Only NMR active

18. Which one of the following gases of diatomic molecules is Raman, infrared, and NMR active?

[GATE 2017]

(a) $^1H - {}^1H$ (b) $^{12}C - {}^{16}O$
(c) $^1H - {}^{35}Cl$ (d) $^{16}O - {}^{16}O$

19. The spacing between two consecutive S-branch lines of the rotational Raman spectra of hydrogen gas is 243.2 cm^{-1}. After excitation with a laser of wavelength 514.5 nm, the Stoke's line appeared at 17611.4 cm^{-1} for a particular energy level. The wavenumber (rounded off to the nearest integer), in cm^{-1}, at which Stoke's line will appear for the next higher energy level is.....

[GATE 2021]

20. It is given that the electronic ground state of a diatomic molecule X_2 has even parity and the nuclear spin of X is 0 . Which one of the following is the CORRECT statement with regard to the rotational Raman spectrum (J is the rotational quantum number) of this molecule?

[GATE 2023]

(a) Lines of all J values are present
(b) Lines have alternating intensity in the ratio of 3:1
(c) Lines of only even J values are present
(d) Lines of only odd J values are present

➢ OTHER EXAMPYQ

1. In the Rotational Raman spectrum of HCl molecule, the displacemnts from the exciting line are represented by

$$\Delta v = \pm(120 + 80J)\text{cm}^{-1}$$

The moment of inertia of the molecule is
(a) 1.4×10^{-47} kg $-$ m^2
(b) 2.8×10^{-47} kg $-$ m^2
(c) 4.2×10^{-47} kg $-$ m^2
(d) 5.6×10^{-47} kg $-$ m^2

Common Data for Q. 3 and Q. 4

The separation between consecutive rotational Raman Stokes line for HCl molecule is 41.6 cm^1. (Given: The reduced mass of HCl molecule is 1.62×10^{-27} kg)

2. The moment of inertia of HCl molecule is
(a) 1.34×10^{-40} kg $-$ m^2
(b) 2.7×10^{-40} kg $-$ m^2
(c) 1.34×10^{-47} kg $-$ m^2
(d) 2.7×10^{-47} kg $-$ m^2

3. The internuclear distance between the atoms of the molecule is
(a) $0.48A^{\circ}$ (b) $0.84A^{\circ}$
(c) $1.30A^0$ (d) $1.95A^0$

4. The selection rule for the allowed rotational Raman lines is
(a) $\Delta J = 0, \pm 2$ (b) $\Delta J = \pm 1$
(c) $\Delta J = 0$ (d) $\Delta I = 0, \pm 1, \pm 2$

5. The first line in the rotational Raman spectra of a diatomic molecule appears with a stokes shift of 12 cm^{-1}. The stokes shift for the second line is
(a) 36 cm^{-1} (b) 24 cm^{-1}
(c) 18 cm (d) 20 cm^{-1}

6. When $^{14}N_2$ (with rotational constant of 1.99 cm^{-1}) is exposed to 340 nm light, then the stokes and anti-stokes line for the molecule in the second rotational state can be observed at
(a) 29412 cm^{-1}, 29410 cm^{-1}
(b) 29366 cm^{-1}, 29402 cm^{-1}
(c) 14779 cm^{-1}, 58529.9 cm^{-1}
(d) 29384 cm^{-1}, 29424 cm^{-1}

Common Data for Q. 7 and Q. 8

7. The rotational constant of $^{14}N_2$ is 2 cm^{-1}. The wave number of the incident radiation in a Raman spectrometer is 20487 cm^{-1}. The wave number of the first scattered Stokes line (in cm^{-1}) of $^{14}N_2$ is
(a) 20479 (b) 20475
(c) 20499 (d) 20495

8. The second rotational Stokes line is expected at (in cm^{-1})
(a) 20467 (b) 20469
(c) 20471 (d) 20475

9. In an experiment, the exciting line of of a sample is observed at 5460 A^0 and stokes line is observed at 5520 A, The wavelength of the anti-stokes line is
(a) 5420 A^0 (b) 5401 A^0
(c) 5380 A^0 (d) 5580 A^0

10. The energy separation between two consecutive stokes lines in Raman Scattering depends on
(a) Energy separation between vibrational levels in the excited state
(b) Wavelength of the incident light
(c) Energy separation between vibrational levels in the ground state
(d) Intensity of the incident light

11. The vibrational constants ω_0 and $\omega_0 x_0$ of HCl are 2937.5 cm^{-1} and 51.6 cm^{-1}. The first Raman stokes line will be observed at (in cm^{-1})
(a) 2989.1 (b) 2885.9
(c) 2834.3 (d) 3040.7

12. The intensity of the electronic $0-0$ band of a diatomic molecule is very intense when the minimum of the potential curve for the upper electronic state lies (here r is the internuclear distance).
(a) at the same value r as that of the lower potential curve
(b) at a smaller value of than that of the lower potential curve
(c) at a larger value of r than that of the lower potential curve
(d) above the dissociation level of the lower potential curve

13. Resonance (NMR, ESR etc.) studies in solids provide information about
(a) The electronic structure of single defects
(b) The motion of the spin or of the surrounding
(c) Collective spin excitations
(d) Internal magnetic fields sampled by the spin

14. The vibrational spectrum of a molecule exhibits a strong line with P and R branches at a frequency u_1 and a weaker line at a frequency u_2, the frequency u, isnot shown up. It's vibrational Raman spectrum shows a strongly polarized line at frequency u_3 and no feature u_1 and u_2
(a) The molecule could be linear
(b) The molecule lacks a center of inversion
(c) $\mathbf{u}_1$ arises from a symmetric stretching mode
(d) $\mathbf{u}_3$ arises from a bending mode

15. Consider the following statements about molecular spectra
P. CH_4 does not give pure rotational Raman lines
Q: SF_6 could be studied by rotational Raman spectroscopy
R. N_2 shows infrared absorption spectrum
S: CH_3CH_3 shows vibrational Raman and infrared absorptin lines
I. H_2O_2 shows pure rotational spectrum
Choose the right combination of correct statements
(a) P and Q (b) P, R and T
(c) P, S and T (d) Q and R

16. You are shown a spectrum consisting of a series of equally spaced lines. This could be
(a) The rotational spectrum CO,
(b) The vibrational spectrum of N_2.
(c) The NMR spectrum of CH_4
(d) The Mossbauer spectrum of Fe_3O_4.

17. The number of fundamental vibrational modes of CO_2 molecule is:
(a) Four: 2 are Raman active and 2 are infrared active
(b) Four: 1 is Raman active and 3 are infrared active
(c) Three: 1 is Raman active and 2 are infrared active
(d) Three: 2 are Raman active and 1 is infrared active

18. If a molecule has a centre of symmetry then
(a) Raman active vibrations are infrared active
(b) Raman active vibrations are infrared inactive and vice versa
(c) some, but not all, of the Raman active vibrations are infrared active
(d) all vibrations are Raman and infrared inactive.

19. Raman effect is suppressed in
(a) semiconductors (b) dielectrics
(c) metals (d) insulators

20. Match the phrases in Group I and Group II and identify the correct option.
Group-I
(P) Electron spin resonance (ESR)
(Q) Nuclear magnetic resonance (NMR)
(R) Transition between vibrational states of molecule
(S) Electronic transition
Group II
(i) radio frequency
(ii) visible range frequency
(iii) microwave frequency
(iv) far-infrared range
(a) (P-i), (Q-ii), (R-iii), (S-iv)
(b) (P-ii), (Q-i), (R-iv), (S-iii)
(c) (P-iii), (Q-iv), (R-i), (S-ii)
(d) (P-iii), (Q-i), (R-iv), (S-ii)

21. Let the separation of the frequencies of the first Stokes and the first anti-Stokes lines in the pure rotational Raman Spectrum of the H_2 molecule be $\Delta v(H_2)$ while the corresponding quantity for D_2 is $\Delta v(D_2)$. The ratio $\frac{\Delta v(H_2)}{\Delta v(D_2)}$ is
(a) 0.6 (b) 1.2
(c) 1 (d) 2

22. The red line of wavelength 644 nm in the emission spectrum of Cd corresponds to a transition from the $^1D_2$ level to the $^1P_1$ level. In the presence of a weak magnetic field, this

spectral line will split into (ignore hyperfine structure)

(a) 9 lines (b) 6 lines
(c) 3 lines (d) 2 lines

23. The Raman rotational-vibrational spectrum of nitrogen molecules is observed using an incident radiation of wavenumber 12500 cm^{-1}. In the first shifted band, the wavenumbers of the observed lines (in cm^{-1}) are 10150,10158,10170,10182 and 10190 . The values of vibrational frequency and rotational constant (in cm^{-1}), respectively, are **[June 2022]**

(a) 2330 and 2, (b) 2350 and 2,
(c) 2350 and 3, (d) 2330 and 3,

24. In the absorption spectrum of H-atom, the frequency of transition from the ground state to the first excited state is v_H. The corresponding frequency for a bound state of a positively charged muon (μ^+)and an electron is v_μ. Using $m_\mu = 10^{-2}$ kg, $m_e = 10^{-30}$ kg and $m_p \gg m_e, m_\mu$, the value of $(v_\mu - v_H)/v_H$ is

(a) 0.001 , (b) 0.001,
(c) -0.01 , (d) 0.01,

25. The $|3,0,0\rangle$ state (in the standard notation $|n,l,m\rangle$) of the H-atom in the non-relativistic theory decays to the state $|1,0,0\rangle$ via two dipole transitions. The transition route and the corresponding probability are **[June 2021]**

(a) $|3,0,0\rangle \rightarrow |2,1,-1\rangle \rightarrow |1,0,0\rangle$ and $\frac{1}{4}$
(b) $|3,0,0\rangle \rightarrow |2,1,1\rangle \rightarrow |1,0,0\rangle$ and $\frac{1}{4}$
(c) $|3,0,0\rangle \rightarrow |2,1,0\rangle \rightarrow |1,0,0\rangle$ and $\frac{1}{3}$
(d) $|3,0,0\rangle \rightarrow |2,1,0\rangle \rightarrow |1,0,0\rangle$ and $\frac{2}{3}$

26. Diffuse hydrogen gas within a galaxy may be assumed to follow a Maxwell distribution at temperature 10^6 K, while the temperature appropriate for the H gas in the inter-galactic space, following the same distribution, may be taken to be 10^4 K. The ratio of thermal broadening $\Delta v_G/\Delta v_{1G}$ of the Lyman- α line from the H-atoms within the galaxy to that from the intergalactic space is closest to

(a) 100 (b) $\frac{1}{100}$ (c) 10 (d) $\frac{1}{10}$

27. The wavelength of the first Balmer line of hydrogen is 656 nm. The wavelength of the corresponding line for a hydrogenic atom with $Z = 6$ and nuclear mass of 19.92×10^{-27} kg is

(a) 18.2 nm (b) 109.3 nm
(c) 143.5 nm (d) 393.6 nm

28. If we take the nuclear spin I into account, the total angular momentum is $\vec{F} = \vec{L} + \vec{S} + \vec{I}$, where $\vec{L}$ and $\vec{S}$ are the orbital and spin angular momenta of the electron. The Hamiltonian of the hydrogen atom is corrected by the additional interaction $\lambda \vec{I} \cdot (\vec{L} + \vec{S})$, where $\lambda > 0$ is a constant. The total angular momentum quantum number F of the p-orbital state with the lowest energy is

(a) 0 (b) 1 (c) 1/2 (d) 3/2

❖ Answer Key

CSIR-NET PYQ				
1. a	2. b	3. b	4. a	5. d
GATE PYQ				
1. c	2. c	3. c	4. c	5. c
6. c	7. a	8. c	9. a	10. d
11. a	12. b	13. c	14. c	15. c
16. 18514	17. c	18. c	19. 17368	20. c
OTHER EXAM PYQ				
1. a	2. a	3. c	4. a	5. d
6. d	7. b	8. a	9. b	10. c
11. c	12. a	13. a,b	14. a	15. c
16. a	17. b	18. b	19. c	20. d
21. d	22. c	23. a	24. c	25. c
26. c	27. a	28. b		

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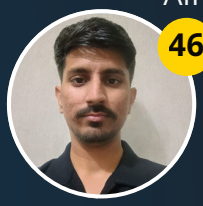

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MANGESH

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170 Marks


SHAILESH

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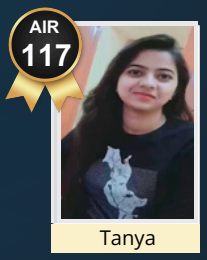

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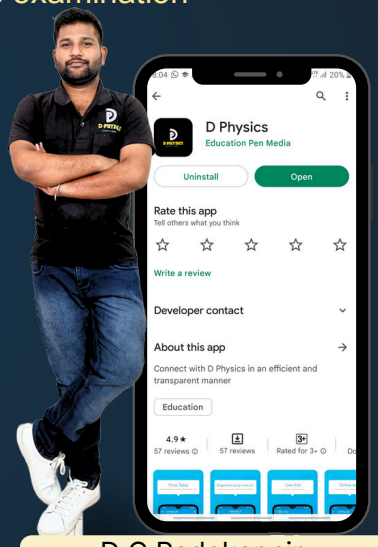

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