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,GATE,JEST,TIFR

1.0 Bohr' Atomic Model

❖ CSIR-NET PYQ

1. Given that the ground state energy of the hydrogen atom is -13.6 eV , then the ground state energy of positronium (which is a bound state of an electron and a positron) is

[NET Dec. 2011]

(a) 6.8 eV (b) -6.8 eV

(c) -13.6 eV (d) 13.6 eV

2. A muon (μ^-)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%

9. The hyperfine splitting of the ground state of the hydrogen atom is given as

$$\Delta E\propto\frac{g_p g_e}{m_p m_e a^3}$$

where g_p and g_e are the nuclear and electron Landê g factors respectively, and a is the orbital radius of the ground state. It is given that g (proton) $=5.59$. In Hydrogen, transition between these split levels corresponds to radiation of wavelength 21 cm .If the proton is replaced by a positron, the corresponding wavelength would be

[NET Dec 2024]

(a)2.6 mm (b) 3.2 mm

(c) 3.2 cm (d)2.6 cm

❖ GATE PYQ

1. The series limit of the Balmer series for hydrogen atom is given as 360 nm. Calculate the atomic number of the element that gives the lowest x-ray wavelength at 0.1 nm of the K-series.

[GATE 2001]

2. 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

3. 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) $\frac{27}{32}\lambda$

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

(a) 0 (b) 1 Ev

(c) +13.6 Ev (d) ∞

5. 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]**

6. 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: $8.617 \times 10^{-5}\,\mathrm{eV/K}$)

[GATE 2020]

7. Which one of the following is a dimensionless constant?

[GATE 2023]

(a) Permittivity of free space

(b) Permeability of free space

(c) Bohr magneton

(d) Fine structure constant

8. The screened nuclear charge of neutral Helium atom is given as $1.7e$, where e is the magnitude of the electronic charge. Assuming the Bohr model of the atom for which the energy levels are $E_n = -\frac{Z^2}{2}\frac{1}{n^2}$ atomic units (Z is the atomic number), the first ionization potential of Helium in atomic units is

[GATE 2025]

(a)0.89 (b)1.78

(c)0.94 (d)3.16

❖ 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) $\frac{c}{1+\alpha}$

(b) $\frac{c}{1+\alpha^2}$

(c) $\alpha^2 c$

(d) αc

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

[JEST 2013]

(a) $\frac{13.6}{2}$ eV (b) 13.6/180eV

(c) 13.6×1810 eV (d) 13.6eV

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 13.377 eV. 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:-

[JEST 2016]

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

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

6. What is the binding energy of an electron in the ground state of a He$^+$ion?

[JEST 2019]

(a) 6.8 ev (b) 13.6 eV

(c) 27.2 eV (d) 54.4 Ev

7. Positronium is a short lived bound state of an electron and a positron. The energy difference between the first excited state and ground state of positronium is expected to be around **[JEST 2021]**

(a) four times that of the Hydrogen atom

(b) twice that of the Hydrogen atom

(c) half that of the Hydrogen atom

(d) the same as that of the Hydrogen atom

8. Given the mass of the proton $m_p \simeq 1836 m_e$ and mass of the deuteron $m_d \simeq 3670 m_e$, where m_e is the electron mass, find the fractional shift (in parts per million, to the nearest integer) of the ground state energy of the deuterium atom as compared to H -atom.

[JEST 2025]

❖ TIFR PYQ

1. Given that the ionization energies of Hydrogen (^1H) and Lithium (^{3}Li) are 13.6 eV and 5.39 eV 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) 1.26 e (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. 0 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) ${}_{1}^{3}\mathrm{H}$ (b) ${}_{1}^{2}\mathrm{H}$

(c) ${}_{2}^{4}\mathrm{He}$ (d) $\mathrm{H}_2\mathrm{O}$

5. The energy of an electron in the ground state of the He atom is -79 eV . 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 1 eV . The ratio of the number of hydrogen atoms in the 2nd 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) $5.62 \times 10-6$

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 13.377 eV , absorbs most of the energy of the electron, and goes into an excited state. The maximum possible fraction $f \equiv \frac{R_{\text{Final}} - R_{\text{Initial}}}{R_{\text{tritial}}}$ 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 (${}_{6}^{12}\mathrm{C}$) orbited by a muon $\mu\left(q=-e, M_\mu=210 m_e\right)$. 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.

[TIFR 2023]

(a) $7560 E_0$ (b) $235 E_0$

(c) $1050E_0$ (d) $1400E_0$

11. The ionization potential of the H atom is 13.598eV. If the mass of a proton is 1.673×10^{-27} kg, the mass of an electron is 9.109×10^{-31} kg and the mass of the D nucleus is 3.344×10^{-27} kg, the ionization potential of the D atom is given by:

[TIFR -2024]

(a) 13.598eV (b) 13.594eV

(c) 13.602eV (d) 27.188Ev

12. The Hamiltonian for a Helium atom is given as $H = H_0 + H_I$, where

$$H_0 = \frac{(p_1^2 + p_2^2)}{2\mu} - \frac{2e^2}{4\pi\epsilon_0 r_1} - \frac{2e^2}{4\pi\epsilon_0 r_2}$$

and

$$H_I = \frac{e^2}{4\pi\epsilon_0 r_{12}}$$

where μ is the reduced mass of the electron, r_1 and r_2 are the distance of the electrons from the nucleus, and r_{12} is the distance between the two electrons. The value of the first ionization potential of the Helium atom is 24.6eV.

What is the correction due to H_I to the ground state energy of the Helium atom, compared to H_0 ? **[TIFR -2024]**

(a) 29.8eV (b) $-$ 29.8eV

(c) 84.2eV (d) -2.6eV

Answer Key

CSIR-NET PYQ's				
1. b	2. b	3. c	4. c	5. a
6. a	7. c	8. c	9. a	
GATE PYQ's				
1. 31	2. a	3. b	4. a	5. 1.06
6. 14	7. d	8. a		
JEST PYQ's				
1. d	2. a	3. a	4. c	5. a
6. d	7. c	8. 272		
TIFR'PYQ's				
1. c	2. b	3. a	4. a	5. 246
6. b	7. c	8. c	9. a	10. d
11. c	12. a			

2.0 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) $\frac{1}{2}a\hbar^2$

(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 3 MeV . The energy difference between the states in its $1f$ orbital is

[CSIR-DEC 2012]

(a) -7 MeV (b) 7 MeV

(c) 5 MeV (d) -5 MeV

4. How much 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) Decrease 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]$3d^2 4s^2$. 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 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) ${}^3\mathrm{F}_{2,3,4}$

(c) ${}^3\mathrm{G}_{3,4,5}$

(d) ${}^3\mathrm{D}_{1,2,3}$

10. If the fine structure splitting between the $2^2\mathrm{P}_{3/2}$ and 2. ${}^2\mathrm{P}_{1/2}$ 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}

11. The value of the Lande g-factor for a fine structure level defined by the quantum numbers $L=1$ and $\mathrm{J}=2$ and $\mathrm{S}=1$, is

[CSIR-JUNE 2018]

(a) 11/6

(b) 4/3

(c) 8/3

(d) 3/2

12. 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

13. 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) ${}^4\mathrm{F}_{9/2}$

(c) ${}^4D_{7/2}$

(d) ${}^4\mathrm{D}_{1/2}$

14. 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

[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 $\frac{2}{3}$

15. The electronic configuration of ${}^{12}\mathrm{C}$ 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) $E(^3P_1) < E(^3P_0) < E(^3P_2) < E(^1D_2)$

16. Helium atom is excited to a state with the configuration ($2s2p$) with an energy 58.3 eV . After some time, this atom spontaneously ejects a single electron. The value of the orbital angular momentum quantum number (l) of the ejected electron in the final state of the system is
(Ionization potential of $\mathrm{He}(1s)^2$ is 24.6 eV)

[NET JUNE 2024]

(a)1 (b)0

(c)2 (d)3

17. Consider the Bromine ion Br^+in its ground state. The atomic number of Br is 35. The fine structure term symbol $\left(^{2S+1}L_J\right)$ under the LS coupling scheme for the lowest energy state of this ion would be

[NET DEC 2024]

(a) $^3P_2$ (b) $^3P_0$

(c) $^1D_2$ (d) $^4S_{3/2}$

18. A hydrogen atom, excited to electronic configuration $3S_{1/2}$ (nL_j notation), relaxes to the ground state via electric dipole transitions. Considering only fine structure and ignoring hyperfine structure, the maximum number of emitted spectral lines is

[NET DEC 2024]

(a)3 (b)6

(c)1 (d)4

❖ GATE PYQ

1. The Lande g-factor for the $^3\mathrm{P}_1$ level of an atom is:

[GATE 2001]

(a)1/2 (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 $\mathrm{J} = 1$ and a positive parity. The corresponding orbital angular momentum L and spin S combinations are

[GATE 2004]

(a) $\mathrm{L} = 0, \mathrm{S} = 1$ and $\mathrm{L} = 2, \mathrm{S} = 0$

(b) $\mathrm{L} = 0, \mathrm{S} = 1$ and $\mathrm{L} = 1, \mathrm{S} = 1$

(c) $\mathrm{L} = 0, \mathrm{S} = 1$ and $\mathrm{L} = 2, \mathrm{S} = 1$

(d) $\mathrm{L} = 1, \mathrm{S} = 1$ and $\mathrm{L} = 2, \mathrm{S} = 1$

5. The spectral terms for a certain electronic configuration are given by $^3\mathrm{D}$, $^1\mathrm{D}$, $^3\mathrm{P}$, $^{1\mathrm{P}}$, ^{5} S, ^{3} S. The term with the lowest energy is

[GATE 2004]

(a) $^{5}\mathrm{S}$
(b) $^{3}\mathrm{P}$

(c) $^{3}\mathrm{D}$
(d) $^{3}\mathrm{S}$

6. The degeneracy of the spectral term $^{3}\mathrm{F}$ is:

(a) 7
(b) 9

(c) 15
(d) 21

7. The Lande g factor for the level $^{3}\mathrm{D}_3$ 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 $^{3}\mathrm{P}$ 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. The L, S and J quantum numbers corresponding to the ground state electronic configuration of Boron $(Z = 5)$ are

[GATE 2004]

(a) $L = 1, S = \frac{1}{2}, J = \frac{3}{2}$

(b) $L = 1, S = \frac{1}{2}, J = \frac{1}{2}$

(c) $L = 1, S = \frac{3}{2}, J = \frac{1}{2}$

(d) $L = 1, S = \frac{3}{2}, J = \frac{3}{2}$

10. 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) $\Delta\ell = 0, \Delta \mathrm{m}_\ell = 0, \pm 1$

(b) $\Delta\ell = \pm 1, \Delta \mathrm{m}_\ell = \pm 1, \pm 2$

(c) $\Delta\ell = \pm 1, \Delta \mathrm{m}_\ell = 0, \pm 1$

(d) $\Delta\ell = \pm 1, \Delta \mathrm{m}_\ell = 0, \pm 2$

11. The sodium doublet lines are due to transitions from $^{2}\mathrm{P}_{3/2}$ and $^{2}\mathrm{P}_{1/2}$ levels to $^{2}\mathrm{S}_{1/2}$ 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

12. 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 $\Gamma_{\ell_1\ell_2}, \Gamma_{s_1s_2}, \Gamma_{\ell_1s_1}, \Gamma_{\ell_2s_2}, \Gamma_{\ell_1s_2}$ and $\Gamma_{\ell_2s_1}$. For the $\mathrm{J} - \mathrm{J}$ coupling scheme to be applicable, the coupling strengths MUST satisty the condition.

[GATE 2005]

(a) $\Gamma_{\ell_1\ell_2}, \Gamma_{s_1,s_2} > \Gamma_{\ell_1s_1}, \Gamma_{\ell_2,s_2}$

(b) $\Gamma_{\ell_1s_1}, \Gamma_{i_2s_2} > \Gamma_{\ell_1\ell_2}, \Gamma_{s_1s_2}$

(c) $\Gamma_{\ell_1s_2}, \Gamma_{\ell_2s_1} > \Gamma_{\ell_1C_2}, \Gamma_{s_1s_2}$

(d) $\Gamma_{\ell_1s_2}, \Gamma_{\ell_2s_1} > \Gamma_{\ell_1s_1}, \Gamma_{s_2s_2}$

13. The principal series of spectral lines of lithium is obtained by transitions between

[GATE 2006]

(a) n S and 2P, $n > 2$
(b) nD and 2P, $n > 2$

(c) nP and 2 S, $n > 2$ (d) nF and 3D, $n > 3$

14. 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 $^2P_1$

15. 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

16. 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) $\cos^{-1}\frac{\sqrt{3}}{2}$

17. 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) $^3D_{7/2}$

18. 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) $\Delta l = 0, \pm 1; \Delta S = \pm 1; \Delta l = \pm 1$

19. The degeneracy of an excited state of nitrogen atom having electronic configuration $1s^2 2s^2 2p^2 3d^1$ is

[GATE 2011]

(a) 6 (b) 10

(c) 15 (d) 150

20. 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 $\left\{\frac{1}{2},\frac{5}{2}\right\}_{3,2}$

21. The emission wavelength for the transition $^1\mathrm{D}_2 \rightarrow {}^1\mathrm{F}_3$ is $3122\dot{A}$. The ratio of populations of the final to the initial states at a temperature 5000 K is $(h = 6.626 \times 10^{-34}\ \mathrm{J.}s, c = 3 \times 10^8\ \mathrm{m/s}, k_B = 1.380 \times 10^{-23}\ \mathrm{J/k})$

[GATE 2014]

(a) 2.03×10^{-5} (b) 4.02×10^{-5}

(c) 7.02×10^{-5} (d) 9.83×10^{-5}

22. 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

[GATE 2016]

23. Which of the following transitions is NOT allowed in the case of an atom, according to the electric dipole radiation selection rule?

[GATE 2016]

(a) $2s - 1s$ (b) $2p - 1s$

(c) $2p - 2s$ (d) $3d - 2p$

24. The number of spectroscopic terms resulting from the L.S. coupling of a $3p$ electron and a $3d$ electron is

[GATE 2016]

25. Using Hund's rule, the total angular momentum quantum number J for the electronic ground state of the nitrogen atom is

[GATE 2017]

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

(c) 0 (d) 1

26. The term symbol for the electronic ground state of oxygen atom is

[GATE 2018]

(a) $^1\mathrm{S}_0$ (b) $^1\mathrm{D}_2$

(c) $^3\mathrm{P}_0$ (d) $^3\mathrm{P}_2$

27. 4Mev γ - rays emitted by the de-excitation of $^{19}\mathrm{F}$ are attributed, assuming spherical symmetry, to the transition of protons from $1d_{3/2}$ state to $1d_{5/2}$ state. If the contribution of spin-orbit term to the total energy is written as $C\langle\vec{l} \cdot \vec{s}\rangle$, the magnitude of C is MeV (up to one decimal place).

[GATE 2018]

28. The ground state electronic configuration of the rare-earth ion ($\mathrm{N}dd^{3+}$) 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]

29. 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]

30. The spin-orbit effect splits the $^2\mathrm{P} \rightarrow {}^2\mathrm{S}$ 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}]

31. Among the term symbols

[GATE 2021]

$$^4S_1,\ ^2D_{7/2},\ ^3S_1 \text{ and } ^2D_{5/2}$$

Choose the option(s) possible in the LS coupling notation.

(a) $^2D_{7/2}$ (b) $^4S_1$

(c) $^3S_1$ (d) $^2D_{5/2}$

32. 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 $s = 1/2, \theta$ 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]

33. An excited state of Ca atom is $[\mathrm{Mg}]3\mathrm{p}^5 4\ \mathrm{s}^2 3\ \mathrm{d}^1$. 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

34. 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

35. 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) $^3S_1$

36. 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?

[GATE 2023]

37. 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) $2k\hbar^2$

38. The effective magnetic moment (in units of Bohr magneton) for the ground state of an isolated $4f$ ion with 6 unpaired electrons in the $4f$ shell according to Hund's rules is (in integer) **[GATE 2025]**

❖ 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. The energy difference between the $3p$ and $3s$ levels in Na is 2.1 eV . 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) 2 Ev (b) 0.2 eV

(c) 0.02 eV (d) 2 meV

5. 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) $-3A_2/4$

5. Consider a stationary electron in a uniform, time-independent magnetic field of strength $B_0/4$ oriented in the $\hat{z}$-direction. The Hamiltonian for this system is expressed as

$$H = -\frac{e}{m}\boldsymbol{S} \cdot \boldsymbol{B}$$

where $\boldsymbol{S}$ is the spin-1/2 operator for electrons. The initial electron spin is oriented in the $\hat{x}$-direction. The spin precession frequency of the electrons is:

[TIFR 2025]

(a) $\frac{|e|\hbar B_0}{4m}$ (b) $\frac{|e|\hbar B_0}{8m}$

(c) $\frac{|e|\hbar B_0}{2m}$ (d) 0

Answer Key				
CSIR-NET PYQ's				
1. d	2. a	3. b	4. c	5. c
6. a	7. d	8. a	9. d	10. c
11. d	12. a	13. a	14. c	15. b
16. a	17. a	18. d		
GATE PYQ's				
1. a	2. b	3. b	4. c	5. a
6. d	7. d	8. a	9. b	10. c
11. d	12. b	13. c	14. b	15. d
16. a	17. b	18. b	19. d	20. a
21. c	22. 0	23. a	24. 12	25. b
26. d	27. 1.6	28. 3.612	29. 3	30. 4
31. c,d	32. 32-93	33. b	34. d	35. a
36. 45	37. b	38. 0-0		
JEST PYQ's				
1. a	2. c	3. a	4. d	5. a
TIFR PYQ's				
1. b	2. a	3. d	4. a	5. a

3.0 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 1 KG 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) ½

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) 12 pm (b) 10 pm

(c) 8 pm (d) 6 pm

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) 1/2 (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) $^{3}\mathrm{F}_2$ (b) $^{3}\mathrm{F}_1$

(c) $^{3}p_1$ (d) $^{3}p_2$

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 $\mu_B/h=1.4\mathrm{MHz}-\mathrm{G}^{-1}$, 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 1 G , is

[NET Dec. 2017]

(a) 10 MHz (b) 1.4 MHz

(c) 5 MHz (d) 2.8 MHz

10. The ground state of sodium atom ($^{11}\mathrm{Na}$) is a $^{2}\mathrm{S}_{1/2}$ 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) $2\mu_\mathrm{B}\mathrm{B}$

(c) $4\mu_\mathrm{B}\mathrm{B}$ (d) $6\mu_\mathrm{B}\mathrm{B}$

11. If the bindings energies of the electron in the K and L shells of silver atom are 25.4 keV and 3.34 keV , respectively, then the kinetic energy of the Auger electron will be approximately

[NET June 2017]

(a) 22 keV (b) 9.3 keV

(c) 10.5 keV (d) 18.7 keV

12. The mean kinetic energy per atom in a sodium vapors lamp is 0.33 eV . Given that the mass of sodium atom is approximately 22.5×10^{9}eV, 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}

16. An atom is subjected to a weak magnetic field $B = 0.1T$. A spectral line of wavelength 184.9 nm corresponding to a $J = 1$ to $J = 0$ transition splits into three components. The highest and the lowest components are separated by 3.2×10^{-4} nm. The magnetic moment of the atom in $J = 1$ state (in units of Bohr magneton) is

[NET JUNE 2025]

(a)2.82 (b) 0.71

(c)1.41 (d)4.23

❖ GATE PYQ

1. The number of hyperfine components observed in the electronic transition $^2p_{L/2} \rightarrow$ $^2S_{L/2}$ 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 $^2D_{5/2} \rightarrow$ $^2P_{3/2}$ 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) $^5l_5 \rightarrow$ $^5H_4$ and (2)$^2D_{5/2} \rightarrow$ $^2P_{3/2}$

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 $^2P_{3/2}$ to $^2S_{1/2}$ 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 $^2P_{3/2}$ and $^2P_{1/2}$ levels to $^2S_{1/2}$ 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 I 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 $Na(3^2P_{1/2} \rightarrow 3^2S_{1/2}, 3^2P_{3/2} \rightarrow 3^2S_{1/2})$ 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: $^2\mathrm{p}_{1/2} \rightarrow {}^2\mathrm{s}_{1/2}$ 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 0.01 nM . 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 $^1\mathrm{P} \rightarrow {}^1\mathrm{D}$ transition is

[GATE 2014]

(a) 3 (b) 4

(c) 8 (d) 9

20. The emission wavelength for the transition $^1\mathrm{D}_2 \rightarrow {}^1\mathrm{F}_3$ 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. The excitation wave length 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]

23. 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). [$e = 1.60 \times 10^{-19}$C, $m_e = 9.11 \times 10^{-31}$ kg, $c = 3.0 \times 10^8$ ms^{-1}]

[GATE 2018]

24. 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: $\sim O\left(\alpha^4 m_e^2 c^2/m_p\right)$
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

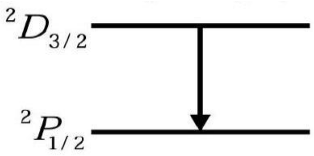
(c) P-4, Q-2, R-1, S-3 (d) P-2, Q-4, R-1, S-3

25. 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]

26. 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]



27. 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]

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

[GATE 2022]

(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

29. 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

30. Which of the following option(s) is/are correct for the ground state of a hydrogen atom?

[GATE 2025]

(a)Linear Stark effect is zero

(b)It has definite parity

(c) Spin-orbit coupling is zero

(d)Hyperfine splitting is zero

❖ 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 $\vec{\mathrm{J}}$ = 0 transition, gets split into three components $\lambda, \lambda \pm \Delta\lambda$. It follows that the Lande g -factor for the transition J = 1 $\underset{\rightarrow}{\mathrm{J}}$ = 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

Answer Key

CSIR-NET PYQ's				
1. b	2. c	3. c	4. b	5. a
6. d	7. b	8. c	9. b	10. b
11. d	12. b	13. a	14. c	15. c
16. c				
GATE PYQ's				
1. a	2. c	3. c	4. d	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. 18515	23. 1.52	24. c	25. 3
26. 6	27. 92	28. b,c	29. b	30. abc
TIFR'PYQ's				
1. d	2. a			

4.0 Rotational Spectroscopy

❖ 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 $938 \text{MeV}/c^2$, 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) 2×10^{-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 $83.03 \text{ cm}^{-1}, 103.73 \text{ cm}^{-1}$, $124.30 \text{ cm}^{-1}, 145.03 \text{ cm}^{-1}$ and 165.51 cm^{-1}. The moment of inertia of the HCl molecule is

$$\left[\text{Take } \frac{h}{2\pi c} = 5.6 \times 10^{-44} \text{ kg} - \text{m}\right]$$

[NET Nov. 2020]

(a) $1.1 \times 10^{-48} \text{ kg} - \text{m}^2$
(b) $2.8 \times 10^{-47} \text{ kg} - \text{m}^2$
(c) $2.8 \times 10^{-48} \text{ kg} - \text{m}^2$
(d) $1.1 \times 10^{-12} \text{ kg} - \text{m}^2$

5. A rigid molecule can have two possible rotational states: $j = 0$ or $j = 1$. Its rotational energies are given by $\epsilon_J = \frac{\hbar^2}{2I} j(j+1)$, where I is its moment of inertia. For an ensemble of such molecules in thermal equilibrium at temperature T, the ratio of the number of molecules in the $j = 1$ state (N_1), to those in $j = 0$ state (N_0), is $\frac{N_1}{N_0} = 0.003$. The temperature T (in units of $\frac{\hbar^2}{2Ik_B}$, where k_B is the Boltzmann constant) is closest to

[NET June 2025]

(a)0.29
(b)0.21
(c)0.15
(d)0.34

❖ 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. 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]

3. 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

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

5. 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

6. In the microwave spectrum of identical rigid diatomic molecules, the separation between the spectral lines is recorded to be $0.7143\ \text{cm}^{-1}$. 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}

7. 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) 1.0 B

8. Three consecutive absorption lines at $64.275\ \text{cm}^{-1}$, $77.130\ \text{cm}^{-1}$ and $89.985\ \text{cm}^{-1}$ 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 $\dfrac{h^2}{12.855hc}\text{gmcm}^2$

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

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

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

9. 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) $\text{P}-3, \text{Q}-2, \text{R}-1, \text{S}-4$
(c) $\text{P}-2, \text{Q}-3, \text{R}-4, \text{S}-1$
(d) $P-1, Q-4, R-2, S-3$

10. 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) $10^6\ \text{cm}^{-1}$ and above
(ii) $10^5-10^6\ \text{cm}^{-1}$
(iii) $108-102\ \text{cm}-1$
(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)

11. 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) $J_A=6, J_B=1$

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

[GATE 2015]

13. 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

(c) (i) - T; (ii) - R, S; (iii) - Q, R; (iv) – S

(d) (i) - S, T; (ii) - P, S; (iii) - R, T; (iv) - S

14. 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

15. 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

[GATE 2024]

(a) $\frac{3}{2}$ (b) $\frac{2}{3}$

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

❖ 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 2.23 meV . 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

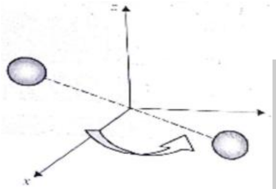
[TIFR 2017]

(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 111μ m. 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) 3.07μ m

5. O_2 is a linear molecule. (The bond length of the oxygen molecule is 1.2Å, and the mass of an oxygen atom is 2.7×10^{-26} kg.) A neutron strikes an O_2 molecule and loses energy by exciting a rotational energy level of O_2. Which of the following is the best estimate of the lowest amount of energy the neutron would have to transfer to the O_2 molecule? (Take the transfer of translational kinetic energy to be negligible.) **[TIFR 2025]**

(a) 3.6×10^{-4}eV (b) 7.2×10^{-4}eV

(c) 1.8×10^{-4}eV (d) 1.4×10^{-3}eV

Answer Key				
CSIR-NET PYQ's				
1. c	2. b	3. b	4. b	5. a
GATE PYQ's				
1. **b**	2. 10*12	3. b	4. b	5. c
6. d	7. a	8. b	9. a	10. b
11. b	12. 10	13. a	14. a	15. a
JEST PYQ's				
1. c				
TIFR'PYQ's				
1. a	2. c	3. d	4. a	5. a

5.0 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 4.34 eV , the electron affinity of Cl is 3.82 eV 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) 8.62 eV (b) 8.16 eV

(c) 4.28 eV (d) 4.14 eV

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) 15.427 eV (b) 11.773 eV

(c) 20.729 eV (d) 6.471 Ev

6. In a rotational-vibrational spectrum of HCl(H^{35}Cl), the first R-branch line and the first P-branch line are observed at $\lambda^{-1}=2906\text{ cm}^{-1}$ and $\lambda^{-1}=2865\text{ cm}^{-1}$, respectively. The equilibrium bond length of this molecule would be closest to

[CSIR-JUNE 2025]

(a)0.2Å (b)1.3Å

(c)13Å (d)2.1Å

❖ 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) $\Delta E_n = \text{constant}, \Delta E_j = \text{constant}$

(b) $\Delta E_n = \text{constan t}, \Delta E_J \propto J$

(c) $\Delta E_n \propto n, \Delta E_J \propto J$

(d) $\Delta E_n \propto n, \Delta E_j \propto J^2$

2. 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.

3. 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 $O - C - O$

4. 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, i i), (Q, iv), (R, i), (S, iii)

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

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

5. The equilibrium vibration frequency for an oscillator is observed at 2990 cm^{-1}. The ratio of the frequencies corresponding to the first overtone 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

6. 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

7. 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 constantx_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) $3\omega_e(1 - 4x_e)$

8. 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]

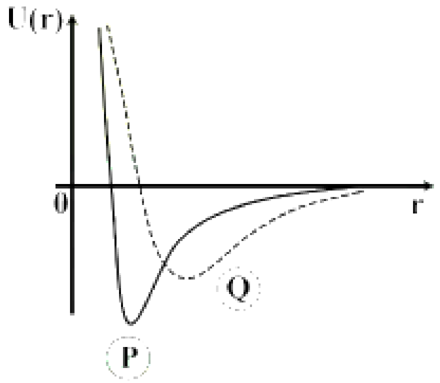
(a) $(m/M)^2$
(b) $(m/M)^{1/2}$
(c) m/M
(d) $(m/M)^{3/2}$

9. 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]

10. Potential energy of two diatomic molecules P and Q of the same reduced mass is shown in the figure. According to this diagram, which of the following option(s) is/are correct?

[GATE 2025]



(a)The equilibrium inter-nuclear distance of Q is more than that of P

(b)The total energy $E = 0$ separates bound and unbound states of the molecules

(c)The lowest vibrational frequency of P is larger than that of Q

(d)Dissociation energy of Q is more than that of P

❖ TIFR PYQ

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

[TIFR 2023]

(a) 17.35 Ev (b) 14.35 eV

(c) 18.85 Ev (d) 5.25 eV

Answer Key				
CSIR-NET PYQ’s				
1. a	2. c	3. c	4. a	5. a
6. b				
GATE PYQ’s				
1. b	2. c	3. d	4. c	5. b
6. c	7. d	8. b	9. 17360.2	10. abc
TIFR’PYQ’s				
1. a				

6.0 Raman Spectroscopy

❖ CSIR-NET PYQ

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 $E_J = BJU+1)$ cm^{-1} where $J = 0,1,2,\ldots.$ and B is a constant Pure rotational Raman transitions follow the selection rule $\Delta \mathrm{J} = 0, \pm 2$. 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 (d) 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 $\Delta v(\mathrm{H}_2)$ 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 1.5μ m incident on a material with a characteristic Raman frquency of 20×10^{12} Hz results in a stokes-shifted line of wavelength [Given : $\mathrm{c} = 3 \times 10^8\ \mathrm{m} \cdot \mathrm{s}^{-1}$]

[GATE 2002]

(a) 1.47μ m (b) 1.57μ m

(c) 1.67μ m (d) 1.77μ m

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 1.5μ m incident on a material with a characteristic Raman frequency of 20×10^{12} Hz results in a Stokes-shifted line of wavelength

[Given: $c = 3 \times 10^8\ \mathrm{m} \cdot\ \mathrm{s}^{-1}$]

[GATE 2004]

(a) 1.47μ m (b) 1.57μ m

(c) 1.67μ m (d) 1.77μ m

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

[GATE 2004]

(a) Raman spectra (b) Infrared spectra

(c) Ultra-violet spectra (d) X-ray spectra

5. 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

6. 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

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) $v_e - 10B, v_e - 14B$

(b) $\mathrm{v_e - 2\ B, v_e - 4\ B}$

(c) $v_e + 10B, v_e + 14B$

(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. 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.

12. The far infrared rotational absorption spectrum of diatomic molecule shows equidistant lines 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}

13. 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}

14. 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)

15. 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]

16. 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

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

[GATE 2017]

(a) $^{1}\mathrm{H}-{}^{1}\mathrm{H}$ (b) $^{12}\mathrm{C}-{}^{16}\mathrm{O}$

(c) $^{1}\mathrm{H}-{}^{35}\mathrm{Cl}$ (d) $^{16}\mathrm{O}-{}^{16}\mathrm{O}$

18. 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]

19. 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

Answer Key				
CSIR-NET PYQ's				
1. a	2. b	3. b	4. a	5. d
GATE PYQ's				
1. c	2. c	3. c	4. b	5. c
6. c	7. a	8. a	9. a	10. d
11. b	12. c	13. c	14. c	15. 18515
16. c	17. c	18. 17368	19. c	

7.0 NMR, ESR, Electronic Spectra

❖ GATE PYQ's

1. The NMR spectrum of ethanol (CH_3CH_2OH) comprises of three bunches of spectral lines. The number of spectral lines in the bunch corresponding to CH_2 group is

[GATE 2006]

(a) 1 (b) 2

(c) 3 (d) 4

2. Match the phrases in group I and group II and identify the correct option

[GATE 2015]

(P) Electron spin resonance (ESR)
(i) radio frequency
(Q) Nuclear magnetic resonance (NMR)
(ii) visible range frequency
(R) Transition between vibrational states of a molecule
(iii) microwave frequency
(S) Electronic transition
(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)

3. 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?

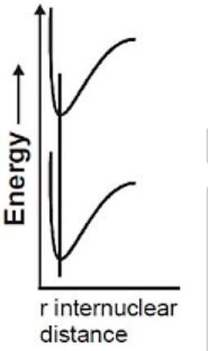
[GATE 2024]

(a) V (b) Cr

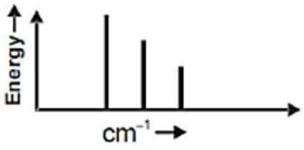
(c) Fe (d) Zn

4. 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

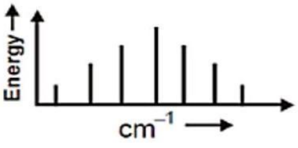
[GATE2009]



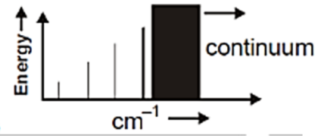
(a)



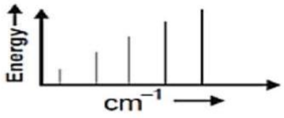
(b)



(c)



(d)



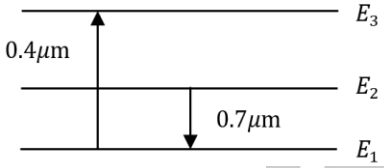
❖ Answer Key

GATE				
1. d	2. d	3. d	4. a	

8.0 Laser and Line Width

❖ CSIR-NET PYQ

1. Consider the energy level diagram (as shown in the figure below) of a typical three level ruby laser system with 1.6×10^{19} Chromium ions per cubic centimeter. All the atoms excited by the 0.4μm radiation decay rapidly to level E_2 which has a lifetime $\tau = 3$ ms



(A) Assuming that there is no radiation of wavelength 0.7μm present in the pumping cycle and that the pumping rate is R atoms per cm^3, the population density in the level N_2 builds up as:

[CSIR JUNE 2011]

(a) $N_2(t) = R\tau\left(e^{l/\tau} - 1\right)$

(b) $N_2(t) = R\tau\left(1 - e^{-t/\tau}\right)$

(c) $N_2(t) = \frac{Rt^2}{\tau}\left(1 - e^{-t/\tau}\right)$

(d) $N_2(t) = Rt$

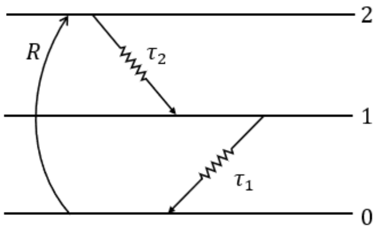
(B) The minimum pump power required (per cubic centimeter) to bring the system to transparency, i.e. zero gain, is

[CSIR JUNE 2011]

(a) 1.52 kW (b) 2.64 kW

(c) 0.76 kW (d) 1.32 kW

2. Consider the energy level diagram shown below, which corresponds to the molecular nitrogen laser.



If the pump rate R is 10^{20} atoms $cm^{-3}\ s^{-1}$ and the decay routes are as shown with $\tau_{21} =$ 20 ns and $\tau_1 = 1\mu s$, the equilibrium populations of states 2 and 1 are, respectively,

[CSIR-DEC 2012]

(a) $10^{14}\ cm^{-3}$ and $2 \times 10^{12}\ cm^{-3}$

(b) $2 \times 10^{12}\ cm^{-3}$ and $10^{14}\ cm^{-3}$

(c) $2 \times 10^{12}\ cm^{-3}$ and $2 \times 10^{6}\ cm^{-3}$

(d) zero and $10^{20}\ cm^{-3}$.

3. Consider a hydrogen atom undergoing a 2P → 1 S transition. The lifetime t_s of the 2P state for spontaneous emission is 1.6 ns and the energy difference between the levels is 10.2eV. Assuming that the refractive index of the medium $n_6 = 1$, the ratio of the Einstein coefficients for stimulated emission $B_{21}(\omega)/A_{21}(\omega)$ is given by

[CSIR-DEC 2012]

(a) $0.683 \times 10^{12}\ m^3\ J^{-1}\ s^{-1}$

(b) $0.146 \times 10^{-12}\ J\ s\ m^{-3}$

(c) $6.83 \times 10^{12}\ m^3\ J^{-1}\ s^{-1}$

(d) $1.463 \times 10^{-12}\ J\ s\ m^{-3}$

4. Consider a He-Ne laser cavity consisting of two mirrors of reflectivity's $R_1 = 1$ and $R_2 =$ 0.98. The mirrors are separated by a distance $d = 20\,\text{cm}$ and the medium in between has a refractive index $n_0 = 1$ and absorption coefficient $\alpha = 0$. The values of the separation between the modes δv and the width Δv_p of each mode of the laser cavity are:

[CSIR-DEC 2012]

(a) $\delta v = 75\text{kHz}, \Delta v_p = 24\text{kHz}$

(b) $\delta v = 100\text{kHz}, \Delta v_p = 100\text{kHz}$

(c) $\delta v = 750\text{MHz}, \Delta v_p = 2.4\text{MHz}$

(d) $\delta v = 2.4\text{MHz}, \Delta v_p = 750\text{MHz}$

5. A gas laser cavity has been designed to operate at $\lambda = 0.5\mu$m with a eavity length of 1 m. With this set-up, the frequency is found to be larger than the desired frequency by 100 Hz. The change in the effective length of the cavity required to retune the laser is

[CSIR-DEC 2013]

(a) -0.334×10^{-12} m

(b) 0.334×10^{-12} m

(c) 0.167×10^{-12} m

(d) -0.167×10^{-12} m

6. The electronic energy levels in a hydrogen atom are given by $E_n = -13.6/n^2$eV. If a selective excitation to the $n = 100$ level is to be made using a laser, the maximum allowed frequency linewidth of the laser is

[CSIR-JUNE 2013]

(a) 6.5MHz (b) 6.5GHz

(c) 6.5 Hz (d) 6.5kHz

7. In a two-state system, the transition rate of a particle from state 1 to state 2 is t_{12}, and the transition rate from state 2 to state 1 is t_{21}. In the steady state, the probability of finding the particle in state 1 is

[CSIR-JUNE 2015]

(a) $\frac{t_{21}}{t_{12}+t_{21}}$ (b) $\frac{t_{12}}{t_{12}+t_{21}}$

(c) $\frac{t_{12}t_{21}}{t_{12}+t_{21}}$ (d) $\frac{t_{12}-t_{21}}{t_{12}+t_{21}}$

8. A positron is suddenly absorbed by the nucleus of a tritium ($^3_1$H) atom to turn the latter into a He^+ion. If the electron in the tritium atom was initially in the ground state, the probability that the resulting He^+ion will be in its ground state is

[CSIR DEC 2015]

(a) 1 (b) $\frac{8}{9}$

(c) $\frac{128}{243}$ (d) $\frac{512}{729}$

9. A He-Ne laser operates by using two energy levels of Ne separated by 2.26eV. Under steady state conditions of optical pumping, the equivalent temperature of the system at which the ratio of the number of atoms in the upper state to that in the lower state will be 1/20, is approximately (the Boltzmann constant $k_b = 8.6 \times 10^{-5}$eV/K).

[CSIR-JUNE 2015]

(a) 10^{10} K (b) 10^{8} K

(c) 10°K (d) 10^{4} K

10. For a two levels system, the population of atoms in the upper and lower levels are 3×10^{18} and 0.7×10^{18}, respectively. If the coefficient of stimulated emission is $3.0 \times 10^5\ \mathrm{m^3/W - s^3}$ and the energy density is $9.0\ \mathrm{J/m^3 - Hz}$, the rate of stimulated emission will be

[CSIR-DEC 2015]

(a) $6.3 \times 10^{16}\ \mathrm{s^{-1}}$
(b) $4.1 \times 10^{16}\ \mathrm{s^{-1}}$
(c) $2.7 \times 10^{16}\ \mathrm{s^{-1}}$
(d) $1.8 \times 10^{16}\ \mathrm{s^{-1}}$

11. The separation between the energy levels of a two-level atom is 2eV. Suppose that 4×10^{20} atoms are in the ground state and 7×10^{20} atoms are pumped into the excited state just before lasing starts. How much energy will be released in a single laser pulse?

[CSIR-JUNE 2016]

(a) 24.6 J
(b) 22.4 J
(c) 98 J
(d) 48 J

12. A two level system in a thermal (black body) environment can decay from the excited state by both spontaneous and thermally stimulated emission. At room temperature (300 K), the frequency below which thermal emission dominates over spontaneous emission is nearest to

[CSIR-DEC 2016]

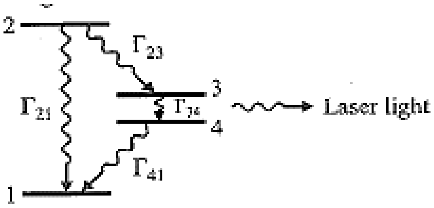
(a) 10^{13} Hz
(b) 10^8 Hz
(c) 10^5 Hz
(d) 10^{11} Hz

13. If the coefficient of stimulated emission for a particular transition is $2.1 \times 10^{19}\ \mathrm{m^3\ W^{-1}\ s^{-3}}$ and the emitted photon is at wavelength 3000Å, then the lifetime of the excited state is approximately.

[CSIR-JUNE 2017]

(a) 20 ns
(b) 40 ns
(c) 80 ns
(d) 100 ns

14. The electronic energy level diagram of a molecule is shown in the following figure.



Let Γ_{ij} denote the decay rate for a transition from the level i and, . The molecules are optically pumped from level 1 to 2. For the transition from level 3 to level 4 to be a lasing transition, the decay rates have to satisfy

[CSIR-JUNE 2018]

(a)$\Gamma_{21} > \Gamma_{23} > \Gamma_{41} > \Gamma_{34}$
(b) $\Gamma_{21} > \Gamma_{41} > \Gamma_{23} > \Gamma_{34}$
(c) $\Gamma_{41} > \Gamma_{23} > \Gamma_{21} > \Gamma_{34}$
(d) $\Gamma_{41} > \Gamma_{21} > \Gamma_{34} > \Gamma_{23}$

15. The cavity of a He-Ne laser emitting at 632.8 nm, consists of two mirrors separated by a distance of 35 cm. If the oscillations in the laser cavity occur at frequencies within the gain bandwidth of 1.3 GHz, the number of longitudinal modes allowed in the cavity is

[CSIR-JUNE 2019]

(a) 1
(b) 2
(c) 3
(d) 4

16. The mean kinetic energy per atom in a sodium vapour 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

[CSIR-DEC 2019]

(a) 7×10^{-7}
(b) 6×10^{-6}
(c) 5×10^{-5}
(d) 4×10^{-4}

17. The energies of the 3 lowest states of an atom are $E_0 = -14\text{eV}, E_1 = -9\text{eV}$ and $E_2 = -7\text{eV}$. The Einstein coefficients are $A_{10} = 3 \times 10^8\ \text{s}^{-1}, A_{20} = 1.2 \times 10^8\ \text{s}^{-1}$ and $A_{21} = 8 \times 10^7\ \text{s}^{-1}$. If a large number of atoms are in the energy level E_2, the mean radiative lifetime of this excited state is

[CSIR-JUNE 2020]

(a) 8.3×10^{-9} s
(b) $1 \times 10^{-8} s$
(c) 0.5×10^{-8} s
(d) 1.2×10^{-8} s

18. Consider a laser cooling experiment where atoms are slowed down by an inelastic process of absorption and subsequent emission of photons. If light of wavelength 776.5 nm is used to slow down potassium atoms (mass number 39) with initial speed 130 ms^{-1}, the number of such absorption and emission cycles needed to bring the atoms to rest is closest to

[CSIR-JUNE 2025]

(a)10^3
(b)10^2
(c)10^5
(d)10^4

❖ GATE PYQ

1. A three level system of atoms has N_1 atoms in level E_1, N_2 in level E_2, and N_3 in level $E_3 (N_2 > N_1 > N_3$ and $E_1 < E_2 < E_3$). Laser emission is possible between the levels

[GATE 2005]

(a) $E_3 \rightarrow E_1$
(b) $E_2 \rightarrow E_1$
(c) $E_3 \rightarrow E_2$
(d) $E_2 \rightarrow E_3$

2. An atom emits a photon of wavelength $\lambda = 600$ nm by transition from an excited state of lifetime 8×10^{-9} s. If Δv represents the minimum uncertainty in the frequency of the photon, the fractional width $\Delta v / v$ of the spectral line is of the order of

[GATE 2005]

(a) 10^{-4}
(b) 10^{-6}
(c) 10^{-8}
(d) 10^{-10}

3. Which one of the following electronic transitions in Neon is NOT responsible for LASER action in a helium neon laser?

[GATE 2006]

(a) $6s \rightarrow 5p$
(b) $5s \rightarrow 4p$
(c) $5s \rightarrow 3p$
(d) $4s \rightarrow 3p$

4. In a He-Ne laser, the laser transition takes place in

[GATE 2007]

(a) He only
(b) Ne only
(c) Ne first, then in He
(d) He first, then in Ne

5. The coherence length of laser light is

[GATE 2008]

(a) directly proportional to the length of the active lasing medium
(b) directly proportional to the width of the spectral line
(c) inversely proportional to the width of the spectral line
(d) inversely proportional to the length of the active lasing medium.

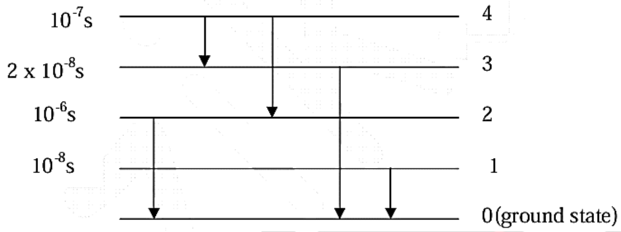
6. When the refractive index μ of the medium changes by $\Delta\mu$ in a laser resonator of length L, the change in the spectral spacing between the longitudinal modes of the laser is (c is the speed of light in free space)

[GATE 2008]

(a) $\frac{c}{2(\mu+\Delta\mu)L}$ (b) $\frac{c}{2\Delta\mu L}$

(c) $\frac{c}{2L}\frac{\Delta\mu}{\mu(\mu+\Delta\mu)}$ (d) zero

7. Five energy levels of a system including the ground state are shown below. Their life-times and the allowed electric dipole transition are also marked.



Which one of the following transitions is most suitable for a continuous wave (CW) laser?

[GATE 2009]

(a) $1 \rightarrow 0$ (b) $2 \rightarrow 0$

(c) $4 \rightarrow 2$ (d) $4 \rightarrow 3$

8. The lifetime of an atomic state is 1 nanosecond. The natural line width of the spectral line in the emission spectrum of this state is of the order of

[GATE 2011]

(a) 10^{-10}eV (b) 10^{-9}eV

(c) 10^{-6}eV (d) 10^{-4}eV

9. The population inversion in a two level laser material cannot be achieved by optical pumping because

[GATE 2011]

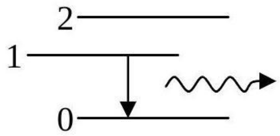
(a) the rate of upward transition is equal to the rate of downward transitions

(b) the upward transition are forbidden but downward transition are allowed

(c) the upward transitions are allowed but downward transition are forbidden

(d) the spontaneous decay rate of the higher level is very low

10. To sustain lasing action in a three-level laser as shown in the figure, necessary condition (s) is (are) **[GATE 2021]**



(a) Lifetime of the energy level 1 should be greater than that of energy level 2

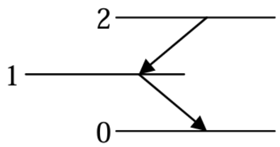
(b)Population of the particles in level 1 should be greater than that of level 0

(c)Lifetime of the energy level 2 should be greater than that of energy level 0

(d)Population of the particles in level 2 should be greater than that of level 1

11. Consider the atomic system as shown in the figure, where the Einstein A coefficients for spontaneous emission for the levels are $A_{2\rightarrow1} = 2 \times 10^7 \text{ s}^{-1}$ and $A_{1\rightarrow0} = 10^8 \text{ s}^{-1}$. If 10^{14} atoms $/\text{cm}^3$ are excited from level 0 to level 2 and a steady state population in level 2 is achieved, then the steady state population at level 1 will be $x \times 10^{13} \text{ cm}^{-3}$. The value of x (in integer) is

[GATE 2021]



❖ JEST PYQ

1. A sodium atom in the first excited 3P states has a lifetime of 16 ns for decaying to the ground 3 S state. The wavelength of the emitted photon is 589 nm. The corresponding line width of the transition (in frequency units) is about

[JEST 2012]

(a) 1.7×10^6 Hz (b) 1×10^7 Hz

(c) 6.3×10^7 Hz (d) 5×10^{14} Hz

2. Which of the following excited states of a hydrogen atom has the highest lifetime?

[JEST 2015]

(a) $2p$ (b) $2s$

(c) 3 s (d) $3p$

3. A continuous He – Ne laser beam ($\lambda = 632.8$ nm) is 'chopped', using a spinning aperture into $1\mu s$ square pulses. The order-of-magnitude estimate of the spectral width $\Delta\lambda$ of the emerging 'pulsed' light is

[JEST 2020]

(a) 10^{-9} m (b) 10^{-12} m

(c) 10^{-15} m (d) 10^{-18} m

❖ TIFR PYQ

1. When light is emitted from a gas of excited atoms, the lines in the spectrum are Doppler-broadened due to the thermal motion of the emitting atoms.

The Doppler width of an emission line of wavelength 500 nanometers (nm) emitted by an excited atom of Argon ($^{40}_{20}$A) at room temperature (27°C) can be estimated as

[TIFR -2012]

(a) 5.8×10^{-4} nm (b) 3.2×10^{-4} nm

(c) 3.2×10^{-3} nm (d) 2.5×10^{-3} nm

(e) 1.4×10^{-3} nm

2. 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.

[TIFR -2016]

Answer Key				
CSIR-NET PYQ's				
1. B&d	2. b	3. a	4. c	5. d
6. b	7. a	8. d	9. d	10.
11. d	12. a	13. c	14. c	15. c
16. b	17. c	18. d		
GATE PYQ's				
1. b	2. c	3. a	4. b	5. a
6. c	7. b	8. c	9.	10. ab
11. 2				
JEST PYQ's				
1. b	2.	3. c		
TIFR'PYQ's				
1. e	2.			