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PHYSICS ACADEMY

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ATOMIC & MOLECULAR PHYSICS

PREVIOUS YEAR'S QUESTIONS WITH ANSWER (CHAPTER-WISE)

- **ATOMIC**
- **MOLECULAR**
- **LASER PHYSICS**

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ATOMIC

1. Given that the ground state energy of the hydrogen atom is –13.6 eV, the ground state energy of positronium (which is a bound state of an electron and a positron) is: **[CSIR-DEC-2011]**

(a) + 6.8 eV (b) – 6.8 eV (c) – 13.6 eV (d) – 27.2 eV

2. If the hyperfine interaction in an atom is given by $H = a\vec{S}_e.\vec{S}_P$ 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) $a\hbar^2$

3. The ratio of intensities of the D_1 and D_2 lines of sodium at high temperature is: **[CSIR-DEC-2011]**

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

4. An atom of mass M can be excited to a state of mass $(M + \Delta)$ by photon capture. The frequency of a photon which can cause this transition is. **[CSIR-DEC-2011]**

(a) $\frac{\Delta c^2}{2h}$ (b) $\frac{\Delta c^2}{h}$ (c) $\frac{\Delta^2 c^2}{2Mh}$ (d) $\frac{\Delta c^2}{2Mh}(\Delta + 2M)$

5. 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. **[CSIR-JUNE-2012]**

(a) $\frac{3}{2}a\hbar^2$ (b) $\frac{1}{2}a\hbar^2$ (c) $3a\hbar^{22}$ (d) $\frac{5}{2}a\hbar^2$

6. The spectral line corresponding to an atomic transition from J = 1 to J = 0 states splits in a magnetic field of 0.1 Tesla into three components separated by 1.6 x 10^{-2} Å.if the zero field spectral line corresponds to 1849 Å, 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

7. A muon (μ^-) from cosmic rays is trapped by a proton to form a hydrogen-like atom. Given that a muon is approximately 200 times heavier than an electron, the longest wavelength of the spectral line (in the analogue of the Lyman series) of such an atom will be. **[CSIR-JUNE-2013]**

(a) 5.62 Å (b) 6.67 Å
(c) 3.75 Å (d) 13.3 Å

8. A perturbation $V_{pert} = aL^2$ added to the Hydrogen atom potential. The shift in the energy level of the 2P state, when the effects of spin are neglected up to second order in a , is **[CSIR-DEC-2013]**

(a) 0
(b) $2a\hbar^2 + a^2\hbar^4$
(c) $2a\hbar^2$
(d) $a\hbar^2 + \frac{3}{2}a^2\hbar^4$

9. The spectroscopic symbol for the ground state of $_{13}$Al 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 **[CSIR-DEC-2013]**

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

10. 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. **[CSIR-JUNE-2014]**

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

11. How much does the total angular momentum quantum number J change in the transition Of Cr($3d^6$) atom as it ionizes to Cr^{2+}($3d^4$)? **[CSIR-JUNE-2014]**

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

12. 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. **[CSIR-DEC-2014]**

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

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13. The effective spin-spin interaction between the electron spin $\vec{S}_e$ and the proton spin $\vec{S}_P$ in the ground state of the Hydrogen atom is given by $H' = a\vec{S}_e.\vec{S}_P$. As a result of this interaction, the energy levels split by an amount. **[CSIR-DEC-2014]**

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

14. Of the following term symbols of the np^2 atomic configurations, $^1S_0$, $^3P_0$, $^3P_1$, $^3P_2$, and $^1D_2$ which is the ground state? **[CSIR-JUNE-2015]**

(a) $^3P_0$ (b) $^1S_0$ (c) $^3P_2$ (d) $^3P_1$

15. The LS configurations of the ground state of ^{12}Mg, ^{13}Al, ^{17}Cl and ^{18}Ar are respectively. **[CSIR-DEC-2015]**

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

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

16. 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) $^3P_0$

17. 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: **[CSIR-JUNE-2016]**

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

18. In the L - S coupling scheme, the terms arising from two non-equivalent p - electrons are **[CSIR-DEC-2016]**

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

19. 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) $\frac{1}{2}$ (d) $\frac{1}{3}$

20. 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. **[CSIR-JUNE-2017]**

(a) $^3F_2$ (b) $^3F_1$ (c) $^3P_1$ (d) $^3P_2$

21. If the binding energies of the electron in the K and L shells of silver atom are 25.4keV and 3.34 keV , respectively, then the kinetic energy of the Auger electron will be approximately. **[CSIR-JUNE-2017]**

(a) 22 keV (b) 9.3keV (c) 10.5keV (d) 18.7 keV

22. Consider a system of identical atoms in equilibrium with blackbody radiation in a cavity at temperature T . The equilibrium probabilities for each atom being in the ground state $|0\rangle$ and an excited state $|1\rangle$ and P_0 and P=1 respectively. Let n be the average number of photons in a mode in the cavity that causes transition between the two states. Let $W_{0\to1}$ and $W_{1\to0}$ denote, respectively, the squares of the matrix elements corresponding to the atomic transitions $|0\rangle \to |1\rangle$ and $|1\rangle \to |0\rangle$. Which of the following equations hold in equilibrium? **[CSIR-DEC-2017]**

(a) $P_0 n W_{0\to1} = P_1 W_{1\to0}$
(b) $P_0 n W_{0\to1} = P_1 n W_{1\to0}$
(c) $P_0 n W_{0\to1} = P_1 W_{1\to0} - P_1 n W_{1\to0}$

(d) $P_0 n W_{0\to1} = P_1 W_{1\to0} + P_1 n W_{1\to0}$

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

$$H_z = \frac{m_J \mu_B B}{J(J+1)}\left(\langle\vec{L}.\vec{J}\rangle + \langle\vec{S}.\vec{J}\rangle\right)$$ **[CSIR-DEC-2017]**

where B is the applied magnetic field, g_s is the g -factor for the spin and $\frac{\mu_B}{h} = 1.4MHz - G^{-1}$, where h is the Planck constant. The approximate frequency shift of the S =0, L =1 and m_s = 1 state, at a magnetic field of 1G, is

(a) 10 MHz (b) 1.4MHz (c) 5MHz (d) 2.8MHz

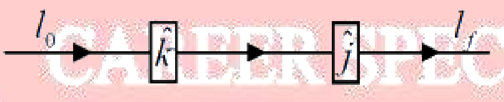
24. The separations between the adjacent levels of a normal multiplet are found to be 22 cm^{-1} and 33 cm^{-1}. Assume that the multiplet is described well by the L □ S coupling scheme and the Lande's interval rule, namely E (J) = - E (J-1)= AJ , where A is a constant. The term notaions for this multiplet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

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

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

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

26. Two Stern-Gerlach apparatus S_1 and S_2 are kept in a line (x -axis). The directions of their magnetic fields are along the positive z and y -axes, respectively. Each apparatus only transmits particles with spins aligned in thee direction of its magnetic field. If an initially unpolarized beam of spin 1/2 particles passes through this configuration, the ratio of intensities $l_0 : l_f$ of the initial and final beams is:



[CSIR-JUNE-2018]

(a) 16 :1 (b) 2 :1 (c) 4 :1 (d) 1: 0

27. 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. **[CSIR-JUNE-2018]**

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

28. The value of the Lande g -factor for a fine-structure level defined by the quantum number L=1, J =2 and S =1, is. **[CSIR-JUNE-2018]**

(a) $\frac{11}{6}$ (b) $\frac{4}{3}$ (c) $\frac{8}{3}$ (d) $\frac{3}{2}$

MOLECULAR

29. A laser operating at 500 nm is used to excite a molecule. If the Stokes line is observed at 770 cm^{-1}, the approximate positions of the Stokes and the anti-Stokes lines are. **[CSIR-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

30. The first absorption spectrum of $^{12}C^{16}O$ 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

31. 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 is938MeV/c^2, then the energy difference ΔE between the two lowest rotational states is approximately. **[CSIR -JUNE-2013]**

(a) 10^{-1} V (b) 10^{-2} eV (c) $2x10^{-2}$ eV (d) 10^{-3}eV

32. If the leading anharmonic correction to the energy of 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. **[CSIR-DEC-2014]**

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

33. 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. **[CSIR-JUNE-2015]**

(a) $\hbar\omega - 3B$ (b) $\hbar\omega - B$

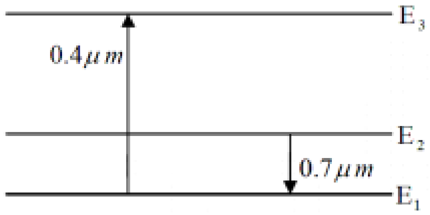
(c) $\hbar\omega + 4B$ (d) $2\hbar\omega + B$

34. 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. Then 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

LASER PHYSICS

35. Consider the energy level diagram (as shown in the figure below) of a typical three level ruby laser system with 1.6 x 10^{19} Chromium ions per cubic centimeter. All the atoms excited by the 0.4 μm radiation decay rapidly to level E_2, which has a lifetime τ = 3 ms. **[CSIR-JUNE-2011]**



A. Assuming that there is no radiation of wavelength 0.7 μm 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]**

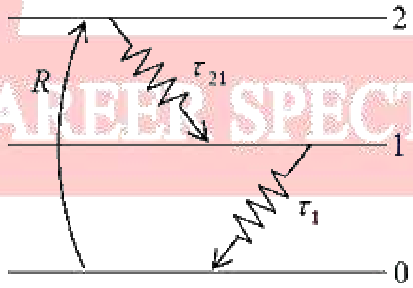
(a) $N_2(t) = R\tau(e^{t/\tau} - 1)$ (b) $N_2(t) = R\tau(1 - e^{t/\tau})$

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

36. Consider the energy level diagram shown below, which corresponds to the molecular nitrogen laser. **[CSIR-DEC-2012]**



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If the pump rate R is 1020 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 x 10^{12} cm^{-3} (b) 2 x 10^{12} cm^{-3} and $10^{14}cm^{-3}$

(b) 2 x 10^{12} cm^{-3} and $10^{14}cm^{-3}$ (d) Zero and 10^{20} cm^{-3}

37. Consider a hydrogen atom undergoing a 2P →1S transition. The lifetime tsp of the 2P state for spontaneous emission is 1.6 ns and the energy difference between the levels is 10.2 eV. Assuming that the refractive index of the medium $n_0 = 1$, the ratio of Einstein coefficients for stimulated and spontaneous emission $B_{21}(\omega)/A_{21}$ is given by. **[CSIR-DEC-2012]**

(a) $0.683 \times 10^{12} m^3 J^{-1} s^{-1}$
(b) $0.146 \times 10^{-12} Jsm^{-3}$
(c) $6.83 \times 10^{12} m^3 J^{-1} s^{-1}$
(d) $1.463 \times 10^{-12} Jsm^{-3}$

38. Consider a He-Ne laser cavity consisting of two mirrors of reflectivity's $R_1 = 1$ $R_2 = 0.98$. The mirrors are separated by a distance d = 20 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) $\delta v = 75kHz, \delta v_p = 24kHz$
(b) $\delta v = 100kHz, \delta v_p = 100kHz$
(c) $\delta v = 750kHz, \delta v_p = 2.MkHz$
(a) $\delta v = 2.MkHz, \delta v_p = 750kHz$

39. 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 line-width of the laser is. **[CSIR-JUNE-2013]**

(a) 6.5 MHz (b) 6.5 GHz (c) 6.5 Hz (d) 6.5 kHz

40. Consider the laser resonator cavity shown in the figure. If I_1 is the intensity of the radiation at M_1 and α is the gain coefficient of the medium between the mirrors, then the energy density of photons in the plane P at a distance x from M_1 is. **[CSIR-JUNE-2013]**

(a) $(I_1/c)e^{-\alpha x}$
(b) $(I_1/c)e^{\alpha x}$
(c) $(I_1/c)(e^{\alpha x} + e^{-\alpha x})$
(d) $(I_1/c)e^{2\alpha x}$

41. A gas laser cavity has been designed to operate at $0.5\mu m$ with a cavity length of1m . 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) $-0.334 \times 10^{-12} m$
(b) $0.334 \times 10^{-12} m$
(c) $0.167 \times 10^{-12} m$
(d) $-0.167 \times 10^{-12} m$

42. For a two level 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 $3.0 \times 10^5 m^3/W - s^{-3}$ and the energy density is 9.0 J / m^3 -Hz , the rate of stimulated
emission will be. **[CSIR-DEC-2015]**

(a) 6.3×10^{18} s^{-1}
(b) 4.1×10^{16} s^{-1}
(c) 2.7×10^{16} s^{-1}
(d) 1.8×10^{16} s^{-1}

43. The separation between the energy levels of a two-level atom is 2 eV . 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

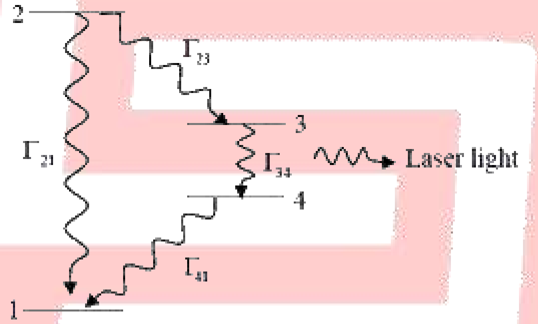
44. A two level system in a thermal (black body) environment can decay from the excited state by both spontaneous and thermally stimulated emission. At room temperature (300K) , the frequency below which thermal emission dominates over spontaneous emission is nearest to. **[CSIR-DEC-2016]**

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

45. If the coefficient of stimulated emission for a particular transition is $2.1 \times 10^{19} m^3 W^{-1} s^{-3}$ and the emitted photon is at wavelength 3000Å then the lifetime of the excited state is approximately. **[CSIR-JUNE-2017]**

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

46. 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 to j . The molecules are optically pumped from level 1 to 2 . For the transition from level 3 to level 4 to be a lassing 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) $\Gamma_{41} > \Gamma_{21} > \Gamma_{34} > \Gamma_{23}$

ANSWER KEY

1.	B	2.	*	3.	D	4.	D	5.	A	6.	C
7.	B	8.	C	9.	C	10.	A	11.	C	12.	A
13.	C	14.	A	15.	C	16.	A	17.	D	18.	D
19.	B	20.	C	21.	D	22.	D	23.	B	24.	D
25.	C	26.	C	27.	C	28.	D	29.	*	30.	C
31.	B	32.	A	33.	C	34.	C	35.	A-(B), B-(C)	36.	B
37.	A	38.	C	39.	B	40.	C	41.	D	42.	None
43.	D	44.	D	45.	C	46.	C	47.		48.	
49.		50.		51.		52.		53.			

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