

## 第六节 原子物理

1. The energy levels of the hydrogen atom are given in terms of the principal quantum number  $n$  and a positive constant  $A$  by the expression

(A)  $A\left(n + \frac{1}{2}\right)$

(B)  $A(1 - n^2)$

(C)  $A\left(-\frac{1}{4} + \frac{1}{n^2}\right)$

(D)  $An^2$

(E)  $-\frac{A}{n^2}$

解：选 (E)。类氢原子能级公式是一定要记住的结论。

2. Which of the following values of the atomic number  $Z$  corresponds to an atom with valence +2 ?

(A) 6

(B) 12

(C) 14

(D) 18

(E) 32

解：原子序数为 12 的原子的电子排布式为

$1s^2 2s^2 2p^6 3s^2$ ，当把最外层两个电子失去后为正

二价。选 (B)。惰性元素的原子序数为 2, 10, 18, ...，所以价态为正二价的原子为 4, 12, 20, 38, ...。

3. A muon is a “heavy electron” with a mass about 200 times of a hydrogen atom is  $E_0$ , the binding energy of a muon-proton atom is most nearly

(A)  $E_0$

(B)  $14 E_0$

(C)  $200 E_0$

(D)  $4000 E_0$

(E)  $40,000 E_0$

解： $\mu$ 子与质子组成原子时， $\mu$ 子的折合质量为

$$\mu = \frac{M_p m_\mu}{M_p + m_\mu} = \frac{1840m_e \times 208m_e}{1840m_e + 208m_e} = 187m_e,$$

而氢原子中电子的折合质量近似为  $m_e$ ，且氢原子能级的大小与折合质量成正比。选 (C)。

4. The anomalous Zeeman effect results from

(A) a nonuniform applied magnetic field

(B) more than one isotope being present

(C) a magnetic moment arising from electron spin

(D) a nuclear quadrupole moment

(E) forbidden atomic transitions

解：反常 Zeeman 效应是电子有自旋的实验证据之一。由于轨道角动量是  $\hbar$  的整数倍，因此必须承认电子有  $\hbar/2$  的自旋才能解释谱线分离为偶数条。(A) 所说内容发生在 Stern-Gerlach 实验中，也是 SUB 考试的重点之一。

5. In a Compton scattering experiment, a collimated beam of monochromatic x-rays of wavelength 0.7 angstrom impinges on a small cylindrical carbon scatter. The scattered radiation is investigated as a function of the angle between it and the primary beam. The scattered radiation contains

(A) no wavelength other than that of the primary beam

(B) a component shifted in wavelength by an amount that is independent of the wavelength of the primary beam

(C) a component shifted in wavelength by an amount that is independent of the scattering angle

(D) a component shifted in wavelength by an amount that decreases as the scattering angle increases

(E) two components with wavelength shifted up and down by equal amounts

解：由 Compton 散射公式

$$\lambda' - \lambda = \frac{h}{m_e c} (1 - \cos \theta),$$

可见波长的变化量与入射波的波长无关，只是角度的函数。答案选 (B)。(D) 不对， $\theta$  增大时（从  $0^\circ$  到  $180^\circ$ ） $\cos \theta$  减小， $\Delta \lambda$  变大。其实  $\theta$  越大表明

碰撞越剧烈，能量损失越大， $\Delta\lambda$ 越大。这里还需要注意一下 Compton 散射公式的适用条件：入射光子能量比较大，波长在 X 射线范围以下。

6. Stern and Gerlach succeeded in deflecting a beam of silver atoms with an inhomogeneous magnetic field. Which of the following is a generally accepted inference from the results of their measurements?

- (A) The technique is useful for precise measurement of magnetic field intensities.
- (B) The single deflection observed is principally due to induced magnetic moment in the silver atom.
- (C) The two deflections observed are due to the two possible measured values of a component of the magnetic moment of the atom.
- (D) The three deflections observed are due to neutral atoms, negatively charged ions, and positively charged ions.
- (E) The continuous range of values observed is due to random orientation of the magnetic moments of the atoms.

解：Stern-Gerlach 实验是重点，要好好复习一下。Stern-Gerlach 实验中原子束偏转后分裂为几条线（而不是连续的一片，答案（E）不对），表明原子角动量只取几个特定的方向。如果原子只有轨道角动量，则条纹数为  $2l+1$ ，但实验观测中会得到偶数条条纹，说明原子中的电子不仅有轨道角动量，还有其他形式的角动量，即自旋。（B）不对，条纹数为 1 说明原子没有固有磁矩。（D）不对，实验中用的是中性原子，产生偏折由其内禀性质决定。正确答案选（C）。

7. The natural line width of an atomic transition with a mean lifetime of  $5 \times 10^{-9}$  second is most nearly

- (A)  $4.1 \times 10^{-15}$  eV
- (B)  $1.3 \times 10^{-11}$  eV
- (C)  $1.3 \times 10^{-7}$  eV
- (D)  $4.1 \times 10^{-2}$  eV
- (E) 13.6 eV

解：由能量—时间测不准关系

$$\Delta E \cdot \tau \geq \frac{\hbar}{2},$$

作为估算，取  $\Delta E \cdot \tau = \hbar$ 。选（C）。

8. The ratio of the spin of the proton to the spin of the electron is most nearly

- (A) 1840
- (B) 650
- (C) 1
- (D) 1/650
- (E) 1/1840

解：质子和电子的自旋均为  $\frac{\hbar}{2}$ ，答案选（C）。注意自旋为粒子的内禀性质，不同于宏观物体的角动量，是量子化的，且与质量无关。其他几个选项显然为迷惑选项。

9. The ground states of the helium, neon, and argon atoms are all

- (A)  $^1S_0$
- (B)  $^2S_{\frac{1}{2}}$
- (C)  $^3S_1$
- (D)  $^1P_1$
- (E)  $^2P_{\frac{1}{2}}$

解：氦、氖、氩为惰性元素，均为满壳层结构，总角量子数  $L$ 、总自旋量子数  $S$  均为 0，从而  $J$  也为 0，所以基态（ $^{2S+1}L_J$ ）为  $^1S_0$ 。选（A）。

10. What are the changes in the mass number  $A$  and atomic number  $Z$  of a nucleus that undergoes electron capture?

- (A)  $A$  is unchanged;  $Z$  decreases by 2.
- (B)  $A$  is unchanged;  $Z$  decreases by 1.
- (C)  $A$  is unchanged;  $Z$  increases by 1.
- (D)  $A$  decreases by 2;  $Z$  increases by 1.
- (E)  $A$  decreases by 4;  $Z$  decreases by 2.

解：电子质量很小，跟原子核相比可忽略，其电量为 -1。原子核捕获一个电子后，使一个质子变为中子，质量数不变而原子序数减 1。选（B）。

11. An element that has an atomic energy level diagram similar to lithium ( $Z=3$ ) has an atomic number equal to

- (A) 9

- (B) 11  
(C) 13  
(D) 15  
(E) 17

解：原子能级以及原子的许多其他性质均由其最外层电子决定。Li 的电子排布式为  $1s^2 2s^1$ ，而 Na ( $Z = 11$ ) 的电子排布式为  $1s^2 2s^2 2p^6 3s^1$ ，最外层均为一个 s 电子，能级相近。选 (B)。

12. The internuclear distance in Angstroms in the hydrogen molecule is most nearly

- (A) 0.01 Å  
(B) 0.1 Å  
(C) 1 Å  
(D) 10 Å  
(E) 100 Å

解：两原子间的精确距离为 0.74Å。考试现场只要想一想 Bohr 半径约为 0.5Å，而两原子之间距离为与这个值数量级相同。选(C)。

13. Which of the following states is possible for an atom with a closed core plus one d-electron ( $l=2$ )?

- (A)  $^3 D_{\frac{5}{2}}$   
(B)  $^4 D_{\frac{3}{2}}$   
(C)  $^2 D_{\frac{1}{2}}$   
(D)  $^2 D_{\frac{5}{2}}$   
(E)  $^3 D_{\frac{1}{2}}$

解：原子基态由最外层电子决定。本题中原子只有一个 d 电子， $l=2$ ，所以总角量子数  $L = 2$ ，总自旋量子数  $S = 1/2$ 。  $J = L+S, L+S-1, \dots, |L-S|$ ，可取值为  $5/2, 3/2$ 。因此原子基态可表示为  $^2 D_{\frac{5}{2}}$  或  $^2 D_{\frac{3}{2}}$ 。选 (D)。

14. If hyperfine structure is ignored, an atomic state  $^2 P_{3/2}$  in a weak external magnetic field will be split

into a number of states equal to

- (A) 2  
(B) 3  
(C) 4  
(D) 5  
(E) 6

解：当外加磁场较弱时，为反常 Zeeman 效应，原子将分裂为  $2J+1$  个态；当外加磁场较强时，为正常 Zeeman 效应（以及 Paschen-Bark 效应），谱线一般分裂为 3 条。本题外加弱磁场， $2 \times 3/2 + 1 = 4$ 。选 (C)。

15. If an electron is in a 4f state, the magnitude of its orbital angular momentum is

- (A)  $\sqrt{2}\hbar$   
(B)  $\sqrt{3}\hbar$   
(C)  $\sqrt{6}\hbar$   
(D)  $2\sqrt{3}\hbar$   
(E)  $4\sqrt{5}\hbar$

解：电子处于 4f 态，4 表示其所处能级，f 代表其角动量量子数为 3。所以角动量平方为

$$l^2 = 3(3+1)\hbar^2,$$

$$l = 2\sqrt{3}\hbar。$$

选(D)。

16. In Compton scattering of a beam of 500-keV x-rays by free electrons initially at rest, which of the following is true of the scattered x-rays?

- (A) They are mostly back-scattered.  
(B) They are scattered isotropically.  
(C) They have less than 500 keV energy.  
(D) They show a left-right asymmetry.  
(E) They are all circularly polarized.

解：由于光子把一部分能量传递给自由静止电子，自身能量下降。或由 Compton 公式

$$\lambda' - \lambda = \frac{h}{m_e c} (1 - \cos \theta)。$$

可见波长变长，能量降低。选 (C)。

17. If  $a_0$  is the radius of the first Bohr orbit in hydrogen, then the radius of the first Bohr orbit of doubly ionized lithium ( $Z = 3$ ) is

(A)  $\frac{a_0}{3}$

(B)  $\frac{a_0}{\sqrt{3}}$

(C)  $a_0$

(D)  $\sqrt{3}a_0$

(E)  $3a_0$

解：类氢原子的基态玻尔半径为

$$a = \frac{\hbar^2}{Z\mu e^2}。$$

因为电子的折合质量近似不变，所以

$$a = \frac{1}{Z} a_0，$$

选 (A)。其实由于核电荷数的增加，类氢原子将电子束缚得更紧，所以基态半径将会变小。

18. A nickel target ( $Z=28$ ) is bombarded with fast electrons. The minimum electron kinetic energy needed to produce x-rays in the K series is most nearly

(A) 10 eV

(B) 100 eV

(C) 1000 eV

(D) 10,000 eV

(E) 100,000 eV

解：考场上作为估算，对于 K 线系，可用氢原子能级公式估算，

$$E = -\frac{\mu e^4}{2\hbar} \frac{Z^2}{n^2} \approx -13.6 \frac{Z^2}{n^2} \text{ eV}。$$

取  $Z=28$ ， $n=1$ ，约为 10,000 eV。选 (D)。严格计算可用 Morsley 公式：

$$\nu_K = 0.248 \times 10^{16} (Z - b)^2, \quad b \sim 1。$$

19. The configuration of the potassium atom in its ground state is  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$ . Which of the following statements about potassium is true?

(A) Its  $n=3$  shell is completely filled.

(B) Its 4s subshell is completely filled.

(C) Its least tightly bound electron has  $l=4$ .

(D) Its atomic number is 17.

(E) Its electron charge distribution is spherically symmetrical.

解：(A) 不对，还有 3d 轨道。(B) 不对，还差一个才满。(C) 不对，最外层电子  $n=4$ ，角动量由 s 表示为  $l=0$ 。(D) 不对，显然为 19。(E) 正确，因为 s 轨道为球对称，而 p 轨道虽不球对称，但由于被全部占满，所以电荷分布仍为球对称。选 (E)。

20. Photons of wavelength  $\lambda$  scatter elastically on free protons initially at rest. The wavelength of the photons scattered at  $90^\circ$  is increased by

(A)  $\lambda/137$

(B)  $\lambda/1836$

(C)  $h/m_e c$ , where  $h$  is Planck's constant,  $m_e$  the rest mass of an electron, and  $c$  the speed of light

(D)  $h/m_p c$ , where  $h$  is Planck's constant,  $m_p$  the rest mass of a proton, and  $c$  the speed of light

(E) zero

解：可以看作广义的 Compton 散射，

$$\lambda' - \lambda = \frac{h}{mc} (1 - \cos \theta)，$$

$m$  为散射物的静止质量。对于本题， $\theta = 90^\circ$ ，

$$\lambda' - \lambda = \frac{h}{m_p c}，$$

选 (D)。请牢记 Compton 散射实验及其公式，否则后果自负。

21. A blackbody at temperature  $T_1$  radiates energy at a power level of 10 milliwatts (mW). The same blackbody, when at a temperature  $2T_1$ , radiates energy at a power level of

(A) 10 mW

(B) 20 mW

(C) 40 mW

(D) 80 mW

(E) 160 mW

解：由 Stefan 定律，黑体的总辐射能力和它的绝对温度的四次方成正比，

$$P = \sigma T^4。$$

选 (E)。

22. The Franck-Hertz experiment and related scattering experiments show that

- (A) electrons are always scattered elastically from atoms
- (B) electrons are never scattered elastically from atoms
- (C) electrons of a certain energy range can be scattered in elastically, and the energy lost by electrons is discrete
- (D) electrons always lose the same energy when they are scattered inelastically
- (E) there is no energy range in which the energy lost by electrons varies continuously

解：即使不知道 Franck-Hertz 试验的具体内容，也可发现选项中只有 (C) 的叙述是正确的。(A)、(B)、(D) 显然不对；(E) 选项，当电子能量较低时，无法触及原子内部，此时为连续散射谱。

23. A transition in which one photon is radiated by the electron in a hydrogen atom when the electron's wave function changes from  $\psi_1$  to  $\psi_2$  is forbidden if  $\psi_1$  and  $\psi_2$

- (A) have opposite parity
- (B) are orthogonal to each other
- (C) are zero at the center of the atomic nucleus
- (D) are both spherically symmetrical
- (E) are associated with different angular momenta

解：由  $\psi_1$  和  $\psi_2$  为球对称可知，二者角量子数均为  $l=0$ ，而跃迁选择定则要求跃迁前后  $\Delta l = \pm 1$ ，所以无法跃迁。选 (D)。

24. The emission spectrum of an atomic gas in a magnetic field differs from that of the gas in the absence of a magnetic field. Which of the following is true of the phenomenon?

- (A) It is called the Stern-Gerlach effect.
- (B) It is called the Stark effect.
- (C) It is due primarily to the nuclear magnetic

moment of the atoms.

- (D) The number of emission lines observed for the gas in a magnetic field is always twice the number observed in the absence of a magnetic field.
- (E) The number of emission lines observed for the gas in a magnetic field is either greater than or equal to the number observed in the absence of a magnetic field.

解：为 Zeeman 或反常 Zeeman 效应，由于磁场的作用使能级简并解除，产生谱线分裂。但正常 Zeeman 效应一般为三分裂，反常 Zeeman 分裂可以是更多条。故答案(D)不对。选 (E)。选项 (B) Stark 效应也可产生谱线分裂，但是是由电场造成的。

25. A spectral line is produced by a gas that is sufficiently dense that the mean time between atomic collisions is much shorter than the mean lives of the atomic states responsible for the line.

Compared with the same line produced by a low-density gas, the line produced by the higher-density gas will appear

- (A) the same
- (B) more highly polarized
- (C) broader
- (D) shifted toward the blue end of the spectrum
- (E) split into a doublet

解：由能量—时间测不准关系，

$$\Delta E \cdot \tau \geq \frac{\hbar}{2}，$$

能级的寿命越长，则其展宽越大。在浓度较大的气体中，由于碰撞比较频繁，能级寿命短，从而谱线宽度大。选 (C)。

26. Sodium has eleven electrons and the sequence in which energy levels fill in atoms is 1s, 2s, 2p, 3s, 3p, 4s, 3d, etc. What is the ground state of sodium in the usual notation  $^{2S+1}L_J$ ?

- (A)  $^1S_0$
- (B)  $^2S_{\frac{1}{2}}$
- (C)  $^1P_0$

(D)  ${}^2P_{\frac{1}{2}}$

(E)  ${}^3P_{\frac{1}{2}}$

解：核外一共 11 个电子，其电子排布式为  $1s^2 2s^2 2p^6 3s^1$ 。总自旋角动量  $S$  和总轨道角动量  $L$  由最外层  $3s$  电子决定。 $S = 1/2$ ,  $L = 0$ ,  $J = 1/2$ ，所以基态为  ${}^2S_{\frac{1}{2}}$ 。选 (B)。

27. Which of the following is NOT compatible with the selection rule that controls electric dipole emission of photons by excited states of atoms?

(A)  $\Delta n$  may have any negative integral value.

(B)  $\Delta l = \pm 1$

(C)  $\Delta m_l = 0, \pm 1$

(D)  $\Delta s = \pm 1$

(E)  $\Delta j = \pm 1$

解：电偶极辐射的跃迁定则为：1. 宇称改变；2.  $\Delta l = \pm 1$ ；3.  $\Delta j = \pm 1$ ,  $\Delta m_l = 0, \pm 1$ 。关键是光子由角动量，但没有自旋，所以  $s$  的值无法改变。

28. The positronium “atom” consists of an electron and a positron bound together by their mutual Coulomb attraction and moving about their center of mass, which is located halfway between them. Thus the positronium “atom” is somewhat analogous to a hydrogen atom. The ground-state binding energy of hydrogen is 13.6 electron volts. What is the ground-state binding energy of positronium?

(A)  $\left(\frac{1}{2}\right)^2 \times 13.6 \text{ eV}$

(B)  $\frac{1}{2} \times 13.6 \text{ eV}$

(C)  $13.6 \text{ eV}$

(D)  $2 \times 13.6 \text{ eV}$

(E)  $(2)^2 \times 13.6 \text{ eV}$

解：利用氢原子能级公式

$$E_n = -\frac{\mu e^4}{2\hbar^2} \frac{1}{n^2}。$$

本题中电子偶素由于正负电子质量相同，折合质

量  $\mu = m_e/2$ ，而氢原子中  $\mu = m_e$ ，所以电子偶素基态能量为氢原子基态能级的一半。选(B)。请牢记氢原子（类氢原子）的能级公式。

29. A beam of electrons is accelerated through a potential difference of 25 kilovolts in an x-ray tube. The continuous x-ray spectrum emitted by the target of the tube will have a short wavelength limit of most nearly

(A) 1 Å

(B) 0.5 Å

(C) 2 Å

(D) 25 Å

(E) 50 Å

解：波长最短的 X 射线对应于获得电子的全部能量，即

$$h\nu_{\max} = h \frac{c}{\lambda_{\min}} = E_e，$$

$$\lambda_{\min} = \frac{hc}{E_e} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{25 \times 10^3 \times 1.6 \times 10^{-19}} = 0.5 \times 10^{-10} \text{ m}$$

。

选 (B)。

30. The Balmer formula for the wavelength of the spectral lines in the visible spectrum of hydrogen may be written as  $1/\lambda = R_H (1/2^2 - 1/n^2)$ . If the wavelength of the  $H_\alpha$  line in the Balmer series is 6563 Angstroms, the wavelength of the series limit is most nearly

(A) 1640 Å

(B) 2281 Å

(C) 3646 Å

(D) 8542 Å

(E) 11,813 Å

解： $H_\alpha$ 线对应于  $n=3$ ，而线系限对应于  $n=\infty$ ，所以

$$\frac{\lambda_\infty}{\lambda_\alpha} = \frac{1/2^2 - 1/3^2}{1/2^2} = \frac{5}{9}，$$

$$\lambda_\infty = \frac{5}{9} \lambda_\alpha = \frac{5}{9} \times 6563 = 3646 \text{ Å}。$$

选 (C)。

31. The following three factors all contribute corrections to the simple calculation of the energy levels of hydrogen.

I. Interaction between the spin of the electron and the spin of the proton

II. Interaction between the spin of the electron and its orbital motion

III. Relativistic variation of the electron's mass  
The corrections due to these factors compare in which of the following ways?

- (A) Those due to I are considerably greater than those due to II and III  
(B) Those due to II are considerably greater than those due to I and III.  
(C) Those due to III are considerably greater than those due to I and II.  
(D) Those due to I and II are considerably and considerably greater than those due to III.  
(E) Those due to II and III are considerably and considerably greater than those due to I.

解：对于氢原子，相对论效应和自旋轨道相互作用对能级的影响由相同的数量级。同时考虑二者的作用可得到精细结构项。而核自旋与电子自旋的耦合较弱，从其名字——超精细结构也可想到它对能级改变很小。选 (E)。

32. The natural line width of an atomic transition with a mean lifetime of  $5 \times 10^{-9}$  second is most nearly

- (A)  $4.1 \times 10^{-15}$  eV  
(B)  $1.3 \times 10^{-11}$  eV  
(C)  $1.3 \times 10^{-7}$  eV  
(D)  $4.1 \times 10^{-2}$  eV  
(E) 13.6 eV

解：根据时间-能量的测不准关系：

$$\Delta E \Delta \tau \geq \frac{\hbar}{2},$$

作为数量级的估算得

$$\Delta E \approx \frac{\hbar}{\Delta \tau \cdot e} \sim 10^{-7} \text{ eV}$$

选 (C)。

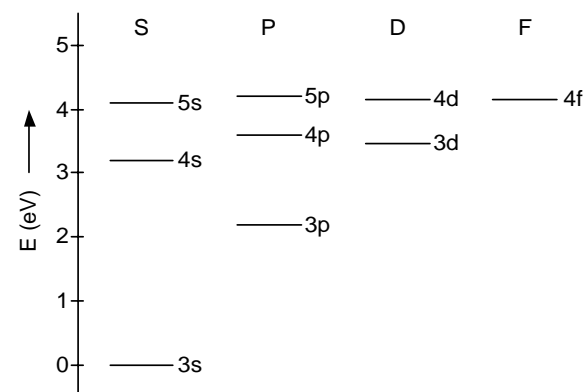
33. If a weak electric field of magnitude  $E$  is applied to an atom in its ground state (Stark effect), what happens to the energy of the atom?

- (A) It is changed by an amount proportional to  $E$ .  
(B) It is changed by an amount proportional to  $E^2$ .  
(C) It is changed by an amount proportional to  $E^3$ .  
(D) It is changed by an amount proportional to  $E^4$ .  
(E) It is not changed.

解：对存在固有电偶极矩的量子态，在弱外电场的作用下，原来对轨道量子数  $l$  简并的能级分裂，裂距正比与电场强度，这就是线性 Stark 效应。选 (A)。但是，值得注意的是，如碱金属原子的能级由于轨道贯穿和极化等效应的影响，它的能级对  $l$  是不简并的，这些能级相应状态的固有电偶极矩为零，因此不存在线性 Stark 效应。在外加电场的作用下，有二级 Stark 效应，或平方 Stark 效应。

#### Question 34-35

A portion of the energy-level diagram for sodium is shown below.



34. Which of the following optical transitions is NOT allowed?

- (A)  $5s - 3p$   
(B)  $4p - 3s$   
(C)  $4p - 4s$   
(D)  $4d - 3s$   
(E)  $3d - 3p$

解：根据跃迁的量子数选择定则，单电子原子允许的跃迁必须满足： $\Delta l = \pm 1$ ，多电子原子允许的跃迁必须满足： $\Delta l = 0, \pm 1$ 。选项 (D) 中的  $l = 2$ ，显然不满足选择定则。选 (D)。

35. For sodium the energy levels with the same principal quantum number  $n$  and with different

angular-momentum quantum numbers  $l$  are different, whereas for hydrogen the energy levels depend only on  $n$ . The principal reason for this is that

- (A) states with different  $l$  values have different spin-orbit splittings.
- (B) in states with smaller  $l$  values, the electron penetrates farther into the electron cloud shielding the nucleus.
- (C) the Pauli exclusion principle allows only two electrons to occupy each state.
- (D) the relativistic change in mass of the electron lowers its energy.
- (E)  $n$  is not a good quantum number.

解：原子的内层电子形成稳固的结构，与原子核构成有效电荷数为+1的原子实。然而，电子对原子实存在极化和贯穿作用：相同主量子数中，角量子数较小的轨道是偏心率较大的椭圆轨道，电子离原子实较近时，极化很强，对能量影响较大。同时，价电子接近原子实的轨道很可能穿入原子实，原子实的有效电荷数就会增加，从而使主量子数  $n$  表示中出现量子数亏损项  $\lambda$ 。选 (B)。

36. Stern and Gerlach succeeded in deflecting a beam of silver atoms with an inhomogeneous magnetic field. Which of the following is a generally accepted inference from the results of their measurements?

- (A) The technique is useful for precise measurement of the magnetic field intensities.
- (B) The single deflection observed is principally due to an induced magnetic moment in the silver atom.
- (C) The two deflections observed are due to the two possible measured values of a component of the magnetic moment of the atom.
- (D) The three deflections observed are due to neutral atoms, negatively charged ions and positively charged ions.
- (E) The continuous range of values observed is due to random orientation of the magnetic moments of atoms.

解：Stern-Gerlach 实验：原子射线束射入不均匀的磁场区域，偏转后在屏上可观测到几条清晰可见的黑斑。这表明原子磁矩只取几个特定的方向，从而原子角动量的投影是量子化的。应用上没有

反过来利用它求磁场的。选 (C)。

37. Positronium is a quasi-atomic system consisting of an electron and a positron. In terms of the ionization energy  $E_0$  of the hydrogen atom, what must be the energy of a photon making a transition from the first excited state of positronium to the ground state?

- (A)  $\frac{3}{2} E_0$
- (B)  $\frac{3}{4} E_0$
- (C)  $\frac{1}{2} E_0$
- (D)  $\frac{3}{8} E_0$
- (E)  $\frac{1}{8} E_0$

解：正负电子对的能级计算与氢原子类似，其等效质量  $m^* = m_H / 2$ 。一些结论

$$a_0' = \frac{4\pi\epsilon_0\hbar^2}{m^*e^2} = 2a_{0H}, E_n' = -\frac{1}{n^2} \frac{e^2}{8\pi\epsilon_0 a_0} = \frac{1}{2} E_{nH}$$

所以，从  $n=1$  到基态的跃迁能量

$$E = E_1' - E_2' = \frac{E_0 - E_0/4}{2} = \frac{3E_0}{8}。$$

选 (D)。

38. If an electron were confined to nuclear dimensions, the uncertainty in its momentum would be most nearly

- (A) 0.2 eV/c
- (B) 200 eV/c
- (C) 200 KeV/c
- (D) 200 MeV/c
- (E) 200GeV/c

解：根据测不准原理直接计算

$$\Delta p \approx \frac{\hbar}{\Delta x} \sim \frac{10^{-34}}{10^{-15}} \frac{c}{e} \sim 10^8。$$

选 (D)。

39. Which of the following is true of the rare earth



elements?

- (A) They are magnetic due to the filling of d shells throughout the series.
- (B) They are nearly indistinguishable chemically because they differ mainly in the filling of the deeply buried 4f shells.
- (C) They are group II elements.
- (D) They are inert gas.
- (E) They are semiconductors.

解：稀土元素：元素周期表的第六周期中，从 $_{58}\text{Ce}$ 到 $_{71}\text{Lu}$ 十四种元素陆续填充 4f 壳层，而 5s、5p 和 6s 保持不变，具有相似的性质，组成稀土元素族。选 (B)。

40. In Compton scattering of a beam of 500-keV x-rays by free electrons initially at rest, which of the following is true of the scattered x-rays?

- (A) They are mostly back-scattered.
- (B) They are scattered isotropically.
- (C) They have less than 500 keV energy.
- (D) They show a left-right asymmetry.
- (E) They are all circularly polarized.

解：Compton 散射指 X 射线被原子散射后发生波长变长的现象，其散射公式应熟记。由于 X 射线与原子中外层电子发生碰撞，把自己能量的一部分转化成了电子的动能，所以 X 射线的能量一定减小了，波长变长。选 (C)。

41. In a Rutherford back-scattering experiment, an alpha particle ( $A = 4$ ) of kinetic energy  $K = 1 \text{ MeV}$  strikes a Si nucleus ( $A = 28$ ) and is scattered by  $180^\circ$ . The kinetic energy of the scattered alpha particle is most nearly

- (A) 0 MeV
- (B) 0.2 MeV
- (C) 0.56 MeV
- (D) 0.75 MeV
- (E) 1 MeV

解：Rutherford 散射可以近似应用经典力学模型。

$$m_\alpha v_0 = m_{\text{Si}} v_{\text{Si}} - m_\alpha v_\alpha$$

$$K = \frac{1}{2} m_\alpha v_\alpha^2 + \frac{1}{2} m_{\text{Si}} v_{\text{Si}}^2$$

由以上两式联立可以解出  $v_{\text{Si}}$ ，从而求出  $K_{\text{Si}}$  来。

选 (C)。

42. A source emits 0.6 watt of visible monochromatic light of wavelength  $6 \times 10^{-7}$  meter. The number of light quanta emitted per second is most nearly

- (A)  $2 \times 10^6$
- (B)  $6 \times 10^7$
- (C)  $2 \times 10^{18}$
- (D)  $6 \times 10^{25}$
- (E)  $6 \times 10^{28}$

解：功率  $P = nhc / \lambda$ ，由此解得

$$n = \frac{P\lambda}{hc} \sim \frac{10^{-7}}{10^{-33} \times 10^8} = 10^{18}。$$

选 (C)。

43. A photon impinges on the surface of a clean copper plate in a vacuum. A retarding potential of 1 volt is necessary to ensure that an emitted photoelectron is thought to rest. If the work function of the copper plate is 4.0 electron volts, the wavelength of the photon is most nearly

- (A) 12,000 Å
- (B) 4000 Å
- (C) 3000 Å
- (D) 2500 Å
- (E) 600 Å

解：根据 Einstein 光电效应的理论

$$\frac{hc}{\lambda} = E_k + A = 5.0 \text{ eV}。$$

由此可解得入射光子的波长  $\lambda \approx 2500 \text{ Å}$ 。选 (D)。

44. Oxygen, which has atomic number 8, has the ground state configuration given by which of the following? (The notation  $nl^k$  means that there are k electrons with principal quantum number n and angular momentum l).

- (A)  $1s^2 2s^2 2p^4$
- (B)  $1s^2 2s^2 3s^2 4s^2$
- (C)  $1s^2 2s^2 2p^2 3s^2$
- (D)  $1s^2 2p^2 3d^2 4f^2$

(E)  $1s^1 2s^1 3s^1 4s^1 2p^1 3p^1 4p^1 3d^1$

解：O 是第二周期的第六号元素，基态原子核外第三壳层和第四壳层都是空的。基态的电子组态为  $1s^2 2s^2 2p^4$ 。选 (A)。

45. Which of the following atomic transitions CANNOT occur through the emission of electric dipole radiation?

(A)  $p_{1/2} \rightarrow d_{3/2}$

(B)  $p_{3/2} \rightarrow f_{5/2}$

(C)  $p_{1/2} \rightarrow s_{1/2}$

(D)  $p_{3/2} \rightarrow d_{3/2}$

(E)  $p_{3/2} \rightarrow d_{5/2}$

解：根据电偶极跃迁的选择定则，对单电子原子跃迁，

$$\Delta l = \pm 1, \Delta j = 0, \pm 1;$$

对多电子原子 LS 耦合，

$$\Delta S = 0, \Delta L = 0, \pm 1, \Delta j = 0, \pm 1 \quad (0 \rightarrow 0 \text{ 除外})$$

$p_{3/2} \rightarrow d_{5/2}$  的跃迁  $\Delta l = 2$ ，是不允许的。选 (B)。

46. The nondegeneracy of the  $2p_{1/2}$  and  $2p_{3/2}$  levels of the hydrogen atom is an example of

(A) Zeeman splitting

(B) Stark splitting

(C) Fine structure

(D) Hyperfine structure

(E) Lamb shift

解：对氢原子的能级，同时考虑相对论效应和自旋轨道耦合时得到精细结构项。忽略精细结构项时的能级  $E_n$  只与主量子数  $n$  有关，对不同的  $l$  和  $j$  是简并的。考虑精细结构项时的能级  $E_n$  只与  $n$ 、 $j$  有关，对  $l$  无精细结构分裂。具有相同的  $n$ 、 $j$  值不同的  $l$  值的能级分裂，是 Lamb 移位。选 (D)。

47. The energy of the K x-ray emitted by a lead atom is closest to

(A) 100 eV

(B) 1 keV

(C) 10 keV

(D) 100 keV

(E) 1 MeV

解：根据 Moseley 经验公式， $K_\alpha$  线的频率满足

$$\nu_K = 0.248 \times 10^{16} (Z - b)^2, \quad b \sim 1.$$

对铅原子，原子序数  $Z = 82$ ，代入上式后，可求得  $K_\alpha$  线的能量范围。选 (D)。

48. In the Bohr model, the radius of an excited hydrogen atom in the  $n = 100$  state is closest to

(A) 100  $\mu\text{m}$

(B) 10  $\mu\text{m}$

(C)  $5000 \text{ \AA}$

(D)  $1000 \text{ \AA}$

(E)  $50 \text{ \AA}$

解：氢原子的 Bohr 半径  $a_0 = 0.53 \text{ \AA}$ 。对  $n = 100$  的激发态，平均半径

$$a_n = n a_0 = 53 \text{ \AA}.$$

选 (E)。

49. A muon and an antimuon having equal and opposite charges, can form a hydrogenic atom. The masses of the muon and the antimuon are each 207 times the mass of an electron. The magnitude of their charges is the same as the magnitude of the electron's charge. What is the energy of the ground state of this muon-antimuon atom in terms of the ground state energy  $E_0$  of the hydrogen atom?

(A)  $207 E_0$

(B)  $103.5 E_0$

(C)  $E_0$

(D)  $E_0 / 103.5$

(E)  $E_0 / 207$

解：正负介子体系的有效质量

$$m_k^* = 207 m_e / 2 = 103.5 m_e,$$

与氢原子类似

$$E_n' = \frac{1}{n^2} E_0' = \frac{m^*}{m_e} E_n = 103.5 E_n。$$

选 (B)。

50. In the Stern-Gerlach effect, observed when a beam of atoms is passed through an inhomogeneous magnetic field, which of the following is true?

- (A) The atoms must be ionized first.
- (B) No deflection is observed for hydrogen atoms.
- (C) Only one deflection is observed for hydrogen atoms.
- (D) Two distinct deflections are observed for sodium ( $Z = 11$ ) atoms.
- (E) Three distinct deflections are observed for magnesium ( $Z = 12$ ) atoms.

解：Stern-Gerlach 实验中原子射线束的分裂数为  $2j + 1$ ,  $j$  是总角动量量子数。对于基态的 Mg 原子, 电子组态为  $1s^2 2s^2 2p^6 3s^2$ , 最外层电子耦合的原子态为  $^1S_1$ ,  $j = 1$ , 因此分裂成三条线。选 (E)。

51. Two electrons, e.g., those in an excited state of He, interact by a Coulomb potential. If their spins are parallel, the spatial part of the total wave function must be antisymmetric with respect to exchange. This triplet state is lower in energy than the corresponding singlet (antiparallel spins) because in the triplet state the

- (A) magnetic dipole-dipole interaction is weaker
- (B) magnetic dipole-dipole interaction is stronger
- (C) electrons are on the average closer together
- (D) electrons are on the average farther apart
- (E) spin-orbit couplings are weaker

解：两个能级的主量子数  $n$  和角量子数  $l$  相同, 对总角动量量子数  $j$  的分裂属于精细结构分裂, 是自旋轨道耦合的结果。选 (E)。

52. Which of the following properties of the hydrogen atom can be predicted most accurately from the simple Bohr model?

- (A) Energy differences between states
- (B) Angular momentum of the ground state
- (C) Degeneracy of states
- (D) Transition probabilities

(E) Selection rules for transitions

解：Bohr 模型计算出一套能级公式。那么人们如何去检验它呢, 只有氢原子光谱, 从中得出各能级间的能量差。Bohr 模型正是因为正确解释了氢原子光谱而名气斐然的。选 (A)。

53. The total energy necessary to remove all three electrons from a lithium atom is most nearly

- (A) 2 MeV
- (B) 2 KeV
- (C) 200 eV
- (D) 20 eV
- (E) 2 eV

解：类氢原子能级公式

$$E_n = -\frac{\mu Z^2 e^4}{\hbar^2 n^2}。$$

锂,  $Z = 3$ , 所以它最后一个电子的电离能为

$$9E_0 = 9 \times 13.6 = 122 \text{ eV}。$$

而由于屏蔽作用以及距离变大, 外层的电子的电离能比内层要小, 所以第一、第二电离能为几十个 eV 的数量级。选 (C)。