Atomic Theory

Answers and Explanations

1. B

The atomic weight of an element is the weighted mean of the relative atomic masses of all isotopes of that element weighted to reflect each isotope's abundance on Earth. For example, the atomic weight of the element chlorine is 35.45u. This is determined by averaging the atomic masses and relative abundances of its two main naturally occurring isotopes, which have atomic masses of 34.97u (76%) and 36.97u (24%).

2. C

Photon energy equals the product of Planck's constant ($h = 6.63 \times 10^{-34}$ J·s) and the frequency of the light.

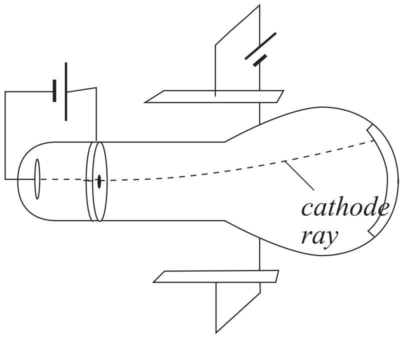
$$E = hf$$

3. D

The law of multiple proportions, sometimes called Dalton's Law, was a key proof of atomic theory. The law states that if two elements form more than one compound between them, then the ratios of the masses of the second element combined with a fixed mass of the first element will always be ratios of small whole numbers.

4. C

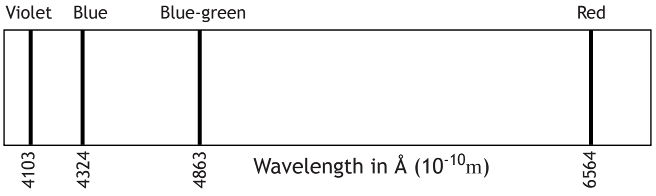
A cathode ray is a stream of electrons produced in a particular type of vacuum tube apparatus, ie. an evacuated glass tube equipped with two electrodes across which a powerful voltage is applied.



Cathode ray tubes played an important role in the history of atomic theory. In 1897 J. J. Thomson demonstrated that cathode rays were made of particles approximately 1800 times lighter than hydrogen atoms. In other words, the first subatomic particle to be discovered, the electron, was characterized using a cathode ray apparatus. Thomson showed the particles of a cathode ray were identical with particles given off by photoelectric and radioactive materials. It was quickly recognized that electrons carry electric currents in metal wires and that electrons are the particles within an atom in possession of negative electric charge.

5. B

When hydrogen atoms are excited by heat or electricity they emit light. However, instead of the continuous spectrum predicted by the classical model of an atom, one observes a line spectrum, with only particular wavelengths represented. Below is a portion of the line spectrum in the visible region for hydrogen.



Bohr reasoned that the line spectrum was evidence that the hydrogen atom electron could exist only in certain discrete, quantized energy states. The energy of the line spectrum photons is related to the energy differences between these states through the Bohr frequency rule: $hf = E_f - E_i$

6. A

In the classical model of the energy of a system of two oppositely charged point charges, the sum of the potential and kinetic energy is less than zero when the system is bound. The distance to zero equals the energy required to pull apart the oppositely charged particles. The Bohr model also presents the hydrogen atom as a system where the sum of potential and kinetic energy is a number less than zero. The energy states are a series of negative numbers. For hydrogen's single electron, the energy of the ground state equals −13.6 eV.

Ionization energy is the minimum energy required to remove an electron from a neutral gaseous atom in the ground state. For hydrogen, this means elevating the electron from −13.6 eV to zero, which is the threshold for the electron to escape from the atom. In other words, the ionization energy of hydrogen is 13.6 eV.

7. C

The orbital angular momentum quantum number, l, also known as the azimuthal quantum number, is the quantum number that determines the shape of the orbital. If $l = 0$, the electron is in an *s* subshell. If $l = 1$, the electron is in an *p* subshell, and if $l = 2$, the electron is in an *d* subshell.

8. B

In the Bohr hydrogen atom, the electron exists in one of a series of allowed orbits, called stationary states. The atom emits a photon when the electron transitions from one stationary orbit to another. The emitted photon energy equals the energy difference of the stationary states, the Bohr frequency rule.

$$hf = E_f - E_i$$

Of the labeled transitions, only the transitions labeled B and D depict an electronic transition in which the electron is falling inward towards the nucleus, decreasing in energy, so those are the only two of the four which correspond to emission of energy. A and C correspond to absorption of energy by the atom.

The vertical scale on the energy diagram is straightforward. The transition from n = 4 to n = 3, labeled B, will be the transition involving the greatest change in energy that produces the shortest wavelength photon. The higher the frequency the shorter the wavelength.

$$E = hf \qquad E = \frac{hc}{\lambda}$$

9. A

Ionization energy is the minimum energy required to remove an electron from a neutral gaseous atom in the ground state. For hydrogen with only a single electron, ionization energy corresponds to the transition of this electron from its position at $n = 1$ to ∞.

10. C

With a ground state electron configuration of $1s^2 2s^2 2p^6$, the electron orbital diagram of neon shows the three *p* orbitals completely occupied.

1*s*	2*s*		2*p*	
(↑↓)	(↑↓)	(↑↓)	(↑↓)	(↑↓)

11. C

By Aufbau principle, the electrons fill the lower energy 1s and 2s orbitals first. The remaining two electrons then, by Hund's rule, go into the 2p orbitals singly with parallel spin.

12. D

For an electron in a *p* orbital, regarding the first three incorrect choices, the principle quantum number must be at least 2 (not at least 1). The angular momentum quantum number must be 1 (not 2). The spin number must be either -½ or ½ (not -1 or 1).

The correct choice is '**D**'. When the angular momentum quantum number is equal to 1, and the electron is within a *p* subshell, the magnetic quantum number could be either -1, 0, or 1. In other words, there are three orbitals within a *p* subshell which the electron might occupy.

13. D

The purpose of this question is to broaden the perspective toward the build-up order for heavier elements. It's okay to miss this question! Textbooks teach the “Madelung order”:

$$1s < 2s < 2p < 3s < 3p < 4s < 3d < 4p < \text{etc.}$$

This order explains the electron configurations of the first three periods of the periodic system and of the first two elements of the forth period, K and Ca. For Ca, for example, 4s < 3d, but for Sc and subsequent 3d < 4s. This is important to remember. The outermost *s* electrons are always the first to be removed in the process of forming transition metal cations.

In the case of ruthenium, because the 4d shell is rather compact, in contrast to the diffuse 5s orbital, the electron repulsion in the d shell increases with increasing d occupation. Eventually, it becomes energetically favorable to shift one of the electrons from the 4d shell into the slightly higher energy 5s orbital.

The basic lesson of this question is not to assume a simple Madelung build-up order for larger atoms.

14. C

Moseley's model relates the photon energy of emitted X-rays to the transition energy of inner shell electrons, which itself depends on nuclear charge, ie. atomic number.

15. B

When an electron falls from the second shell to the first, negative charge is moving closer to positive charge. This represents a decrease in electrostatic potential energy. The energy lost equals the energy of the emitted photon.

16. D

There are many direct and indirect references to the greater energy involved for inner shell transitions of larger atoms compared to hydrogen. The passage describes how Moseley required an X-ray spectrometer to analyze the emission spectra, unlike the UV and visible light spectrometers employed on similar work with hydrogen by researchers such as Ångström and Lyman. X-rays are higher energy photons than UV and visible light. Additionally, Moseley's law for K-alpha lines shows increased energy with increased atomic number, and the passage later refers to the dependence of the transition energy on nuclear charge.

17. A

From the perspective of the rebounding electron, falling from the L shell to the K shell, it is falling towards a nucleus shielded by the single remaining inner shell electron. This is the other electron in the first shell which had not been ejected by earlier the bombardment of the atom.

18. D

Moseley's law for K-alpha lines describes the linear dependence of the square root of emission frequency on atomic number. For simplification, the illustration below bundles all of the constants into '*m*'.

$$E = hf = E_{\mathrm{i}} - E_{\mathrm{f}} = R_{\mathrm{E}}(\mathrm{Z} - 1)^2 \left(\frac{1}{1^2} - \frac{1}{2^2} \right)$$

$$hf = R_{\mathrm{E}}(\mathrm{Z} - 1)^2 \left(\frac{1}{1^2} - \frac{1}{2^2} \right)$$

$$Z = m\sqrt{f} + 1$$