Atomic Theory Practice Items

1. The weighted average mass of the atoms of the stable isotopes of an element as they occur in nature is called the

   A. atomic mass
   B. atomic weight
   C. atomic number
   D. relative isotopic frequency

2. Photon energy

   A. is directly proportional to its wavelength.
   B. is inversely proportional to its frequency.
   C. is directly proportional to its frequency.
   D. equals the wave number.

3. Carbon monoxide has carbon and oxygen in the simple mass ratio 3:4, while carbon dioxide has the ratio 3:8. Similarly, water has oxygen and hydrogen in the simple mass ratio 8:1, while hydrogen peroxide has the ratio of 16:1. These examples illustrate which of the following?

   A. conservation of matter and energy
   B. the Bohr frequency rule
   C. the law of partial pressures
   D. the law of multiple proportions

4. A cathode ray

   A. consist of a stream of positively charged particles.
   B. will not be affected in passing through an orthogonal electric field.
   C. is composed of electrons.
   D. possesses no mass.

5. Analysis of the emission spectrum of hydrogen led Bohr to conclude that

   A. the hydrogen atom consists of an electron and a proton.
   B. electron energy states are quantized.
   C. light comes in discreet packages of energy called quanta.
   D. one cannot determine the exact position of an electron concurrently with its exact momentum.

6. In the Bohr theory of the atom the energy of the n-th level for any atom is given by the following equation

$$E \approx \frac{-13.6Z^2}{n^2}\ \text{eV}$$

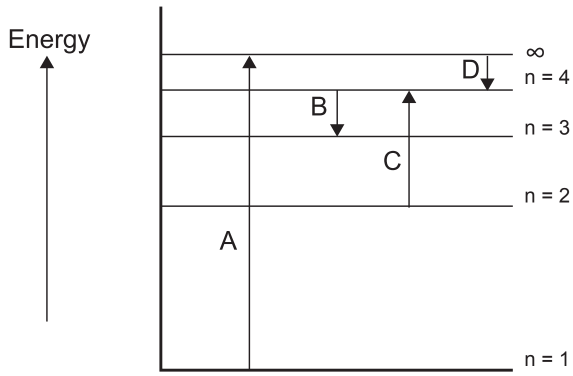
   where Z is the atom's atomic number. Which of the following would be predicted by the Bohr model of the hydrogen atom?

   A. The ionization energy of hydrogen is equal to 13.6 eV.
   B. The electron affinity of hydrogen is equal to 0.75 eV.
   C. The lowest possible energy state of a hydrogen atom is zero.
   D. A longer wavelength photon is absorbed in elevating an electron from the ground state to the 2nd energy level than from the 2nd to the 3rd.

7. In the Schroedinger model, which of the following describes the shape of the orbital inhabited by an electron?

   A. principle quantum number, n
   B. magnetic quantum number, m_l
   C. angular momentum quantum number, l
   D. spin quantum number, m_s

Questions 8 and 9 are based on the following energy level diagram for the hydrogen atom.



8. Of the labeled electronic transitions shown in the figure, photons of the shortest wavelength are being emitted by the atom by the transition labeled:

A. A
B. B
C. C
D. D

9. The arrow representing ionization energy is:

A. A
B. B
C. C
D. D

10. How many p-orbitals are occupied in a ground state Ne atom?

A. 1
B. 2
C. 3
D. 6

11. Which of the following is the proper ground state orbital diagram for neutral carbon?

	1*s*	2*s*	2*p*		
A.	(↑↓)	(↑)	(↑)	(↑)	(↑)
B.	(↑↓)	(↑↓)	(↑)	(↑)	( )
C.	(↑↓)	(↑↓)	(↓)	(↑)	( )
D.	(↑↓)	(↑↓)	(↑↑)	( )	( )

12. An electron exists in a *p* orbital, therefore

A. the principle quantum number is at least 1.
B. the angular momentum quantum number must be 2.
C. the spin number must be either -1 or 1.
D. the magnetic quantum number could be either -1, 0, or 1.

13. Which of the following electronic configurations is the ground state configuration for ruthenium (Z = 44)?

A. [Kr] $5s^2$ $4d^6$

B. [Kr] $4s^2$ $4d^6$

C. [Kr] $4d^8$

D. [Kr] $5s^1$ $4d^7$

The following passage pertains to questions 14-18.

In 1913 Henry Moseley found an empirical relationship between the strongest X-ray line emitted by metals under electron bombardment (then known as the K-alpha line) and their atomic number Z.

In contrast to the UV and visible light spectrometers employed on similar work with hydrogen by researchers such as Ångström and Lyman, Moseley required an X-ray spectrometer for his work with metals. Inside an evacuated glass-bulb electron tube, electrons were fired at a pure metallic substance, causing the ionization of electrons from the inner electron shells of the element. The rebound of electrons into these holes in the inner shells caused the emission of X-ray photons. These exited the tube in a semi-beam, through an opening in the external X-ray shielding. The X-ray photons were next diffracted by a standardized salt crystal, with angular results recorded by X-ray film oriented a fixed distance from the vacuum tube. Analysis of the diffraction pattern allowed the wavelength of the emitted X-rays to be calculated.

The energy lost by an electron dropping from the second shell to the first is described by Moseley's law for K-alpha lines:

$$E = hf = E_i - E_f = R_E(Z - 1)^2 \left(\frac{1}{1^2} - \frac{1}{2^2} \right)$$

Z is atomic number and R_E is the Rydberg constant, equal to 2.180×10^{-18} J.

It was assumed that this X-ray line came from a transition between energy levels with quantum numbers 1 and 2. Moseley's empiric formula was found to be derivable from earlier formulas put forth by Rydberg and Bohr, but the atomic number Z when used in the formula for atoms heavier than hydrogen was diminished by 1 to (Z–1).

At the time it was thought that the innermost "K" shell of electrons should have at least four electrons, so Moseley published his results without a theoretical explanation for the reduction in atomic number by 1. Later, after the inner shell was demonstrated to contain only 2 electrons, it was realized that the effect was caused by charge screening. In the experiment, one of the innermost electrons in the atom is knocked out, leaving a vacancy in the lowest Bohr orbit, which contains a single remaining electron. Therefore, the n=2 electrons aren't pulled inward by the full nuclear charge of +Z but an effective charge of Z–1.

Moseley's law not only established the objective meaning of atomic number, but, as Bohr noted, it established the validity of the nuclear model of the atom with place on the periodic table determined by whole units of nuclear charge.

14. Which of the following statements is true regarding Moseley's model of X-ray production by metal atoms under electron bombardment?

- **A.** The model could account for the emission spectrum of hydrogen.
- **B.** The model was based on the wave properties of the electron.
- **C.** The model was successful in explaining the systematic variation of X-ray emission spectra with atomic number.
- **D.** The model provided the first coherent description of the photoelectric effect.

15. Following the ejection by X-rays of electrons from the inner shells of metal atoms, the rebound of electrons into these holes

- **A.** causes ionization of the metal atom.
- **B.** corresponds to a decrease in the energy of the metal atom.
- **C.** occurs across a distance equal to the wavelength of the emitted X-ray.
- **D.** occurs with absorption of an X-ray.

16. Which of the following can be deduced from the information presented in the passage?

A. X-rays are required to ionize larger metal atoms.
B. An electron transition from the K shell to the L shell may cause a metal atom to release an X-ray photon.
C. An X-ray photon is produced by ionization when a high energy electron collides with a ground state metal electron.
D. The transition energy for an electron from quantum number 2 to 1 is greater with large atoms than with hydrogen.

17. Why is the appropriate charge for the nucleus acting on a rebounding electron from the n=2 shell equal to (Z – 1) in the Moseley formula?

A. An electron in the lowest Bohr orbit screens the nuclear charge.
B. The ejected electron leaves a vacancy in the lowest Bohr orbit.
C. It was thought that the innermost shell should have at least four electrons.
D. The emission of a positron decreases the nuclear charge.

18. Which of the following data might have been collected during the empirical derivation of Moseley's Law?

A. a graph showing a geometric increase in emission wavelength with atomic number
B. a graph showing logarithmic increase of emission frequency with atomic number
C. a graph showing an exponential increase in emission frequency with atomic number.
D. a linear plot of the square root of X-ray frequency against atomic number

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.

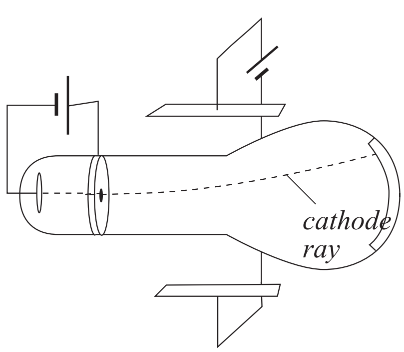
$$E = hf$$

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

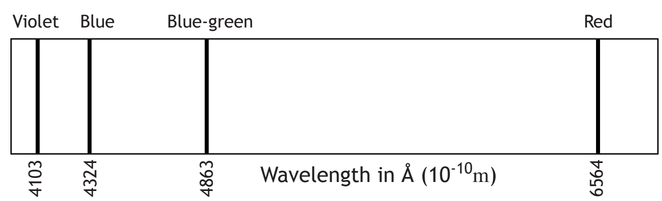
A cathode ray is a stream of electrons produced in a particular type of vacuum tube apparatus, ie. an evacuated glass tube equipped with two electrodes across which a powerful voltage is applied.



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*'.

$$E = hf = E_i - E_f = R_E(Z - 1)^2 \left(\frac{1}{1^2} - \frac{1}{2^2}\right)$$

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

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