Physics 30 – Act. 7.5

Atomic Physics Pre-Test

Due Date: ______________________

1. Describe in point form the main ideas for each atomic model (in chronological order)

Dalton's atom

Dalton's Theory

Dalton's atomic model described atoms as indivisible spheres, like billiard balls. Thomson's experiment on the charge-to-mass ratio of cathode rays produced the key evidence that conflicted with Dalton's theory. Thomson found that cathode rays consisted of negatively charged particles that were much smaller than the smallest atom (hydrogen). This discovery meant that atoms were not indivisible and that they contained small negatively charged particles (electrons).

Thomson's plum-pudding atom

Thomson's Theory

In Thomson's "raisin bun" model, the atom consisted of a positively charged sphere containing a sufficient number of embedded electrons to keep the whole atom neutral. Rutherford's scattering experiment produced the key evidence that conflicted with this model. In this experiment, most of the alpha particles fired at a thin gold foil travelled almost straight through the foil, a few were scattered at very large angles, and occasionally, an alpha particle actually bounced back from the foil. This evidence suggested that the atom was mostly empty space with a very small positive core, and not a uniform positively charged sphere.

Rutherford's Theory

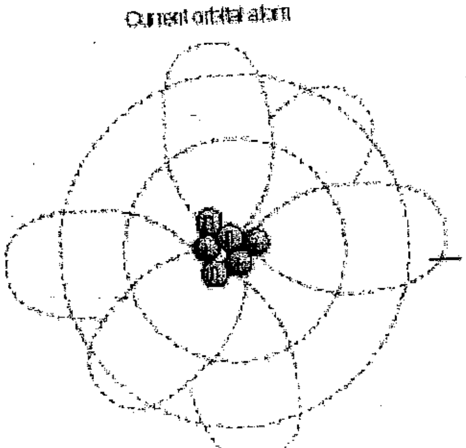
Rutherford's atomic model is like a planetary model. The negatively charged electrons occupy most of the space within an atom and orbit the small positively charged nucleus. However, experiments had shown that an accelerating charge, like an electron, continually loses energy by radiating electromagnetic waves. The electrons should, therefore, spiral into the nucleus and the atom should collapse. Atoms are generally very stable and do not collapse. Therefore, orbiting electrons, as described by Rutherford's model, are inconsistent with the evidence.

Bohr's planetary atom

Bohr's Theory

In Bohr's model, electrons occupy only certain orbits, each with a specific energy. Both the orbits and the energies are quantized. Electrons do not radiate energy as long as they stay in their orbit (stationary state). Only when the electron jumps from one energy level to another does it emit or absorb energy.
Bohr's model still retains the atom as a specific entity (as in Dalton's model), still contains electrons (as in Thomson's model) and still contains a nucleus (as in Rutherford's model).

Current orbital atom



We cannot visualize the quantum mechanical model of the atom as we did with the Bohr model.

The best we can do is describe the electron in terms of probabilities.

These probability patterns are referred to as orbitals or electron clouds.

The shapes and dimensions of the orbitals are found mathematically.

2. An electron enters a magnetic field of 85.0 mT and deflects into a circular arc with radius 7.8 mm. Calculate the kinetic energy of the electrons in eV.

deflected so... $F_m = F_c$

$$q v B_\perp = \frac{mv^2}{R}$$

$$\frac{qBR}{m} = v$$

$$\frac{(1.60\times10^{-19})(85\times10^{-3})(7.8\times10^{-3})}{9.11\times10^{-31}} = v$$

$$1.16\times10^{8}\ m/s$$

$$E_k = \frac{1}{2}mv^2$$

$$E_k = \frac{1}{2}(9.11\times10^{-31})(1.16\times10^{8})^2$$

$$E_k = \frac{6.176\times10^{-15}\ J}{1.6\times10^{-19}\ J/eV} = 3.86\times10^{4}\ eV$$

3. Use data book constants to calculate the q/m ratio for an electron, proton and alpha particle.

electron $\frac{q}{m} = \frac{1.60\times10^{-19}\ C}{9.11\times10^{-31}\ kg} = 1.76\times10^{11}\ C/kg$

proton $\frac{q}{m} = \frac{1.60\times10^{-19}\ C}{1.67\times10^{-27}\ kg} = 9.58\times10^{7}\ C/kg$

α^{2+} $\frac{q}{m} = \frac{3.20\times10^{-19}\ C}{6.65\times10^{-27}\ kg} = 4.81\times10^{7}\ C/kg$

4. The q/m ratio for a potassium ion is 2.54 X 10⁶ C/kg. If the ion were accelerated to a velocity of 4.72 X 10⁵ m/s and then deflected into a radius of 8.1 cm, calculate the strength of the magnetic field causing the deflection.

$$F_m = F_c$$

$$qvB = \frac{mv^2}{R}$$

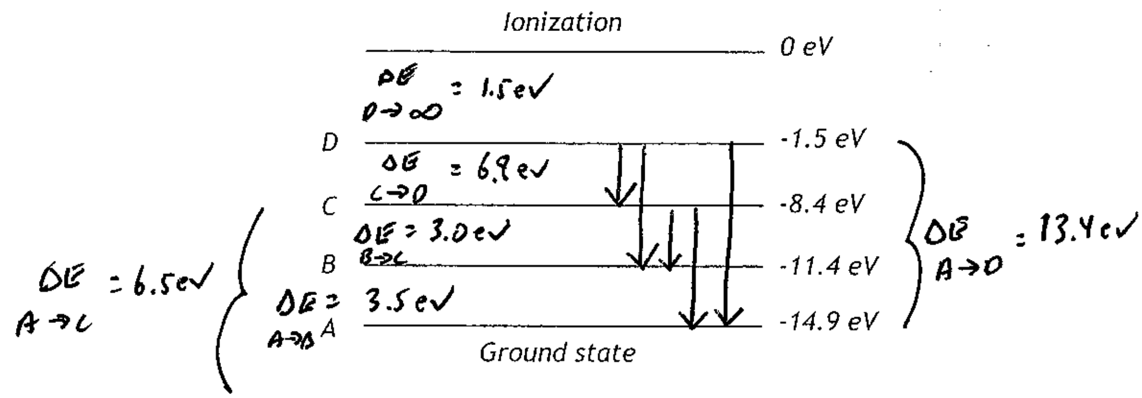
$$qB = \frac{mv}{R}$$

$$\frac{q}{m} = \frac{v}{BR}$$

$$2.54\times10^{6} = \frac{4.72\times10^{5}}{B_\perp \cdot 8.1\times10^{-2}}$$

$$B_\perp = 2.8\ T$$

5. Consider an incident electron with 14.2 eV of kinetic energy. It collides with an electron of an unexcited gas atom (see diagram)
(ground state)



a) Determine the maximum level the atom's electron could be excited to?

The transition from A → D requires 13.4 eV leaving the incident e⁻ with 0.80 eV

b) Determine the number of photons of different wavelengths that could possibly be produced due to an electron at level D moving back towards ground state. (Show the transitions on the diagram)

5 transitions, each will produce a particular frequency of light (bright line spectra)

c) If the electron only excited this gas to level C, determine the kinetic energy retained by the incident electron. Exciting the e⁻ from A → C requires $\Delta E_{A\to C} = E_f - E_i = -8.4 - (-14.9) = 6.5\ eV$

This leaves 14.2 eV − 6.5 eV = 7.7 eV left over as E_k for the incident e⁻.

d) Is there enough energy left over to excite another gas atom? If so, to what level?

A second atom could be excited from level A → C as this transition requires 6.5 eV

e) Which scientist proposed the atomic model in this question?

Bohr atom – atoms can emit and absorb only particular (quantized) amounts of energy.

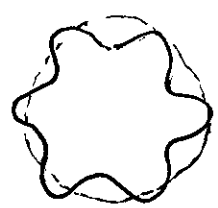
6. Which experiment was used to show that particles can behave as waves? Briefly describe.

Using crystals as a diffraction grating, electrons were shown to produce an interference pattern (nodes and antinodes). Remember that diffraction and interference are <u>wave</u> properties.

7. Calculate the deBroglie wavelength of an electron travelling at 10% of c.

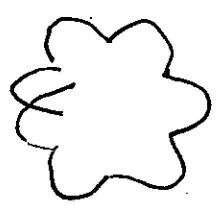
$$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \cdot (.10 \times 3 \times 10^{8})} = 2.43 \times 10^{-11}\, m$$

8. How does the wave mechanical model (also called the quantum mechanical model) predict where electrons can exist around a nucleus. Hint see page 299 example on bottom.



Electrons have a wave nature. The electron (wave) can only exist when the circumference of the orbit is equal to a whole number of λ's (constructive interference)

$2\pi R = n\lambda$ (circumference; n = whole #)



when there are not whole λ's destructive interference occurs and an e⁻ cannot exist at that location.

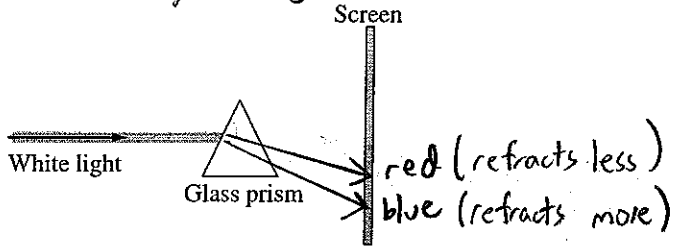
9. Classical physics is the physics of large objects we encounter in everyday life (throwing a baseball, stopping a car at a red light etc.)
Quantum mechanics is the description of motion in an __atomic__ or __sub atomic__ environment that considers the __wave__ characteristics and __probabilities__ of particle behavior.

Quantum mechanics is primarily mathematical.

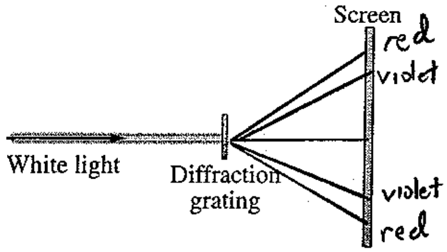
Sample Response

10. To separate the light you may use either a prism or a diffraction grating.

Light passing through a prism is refracted by differing amounts based on the incident wavelength, as described by Snell's law, $\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2}$. Shorter wavelengths refract more than longer wavelengths and deviate from the original path by a greater amount, as shown below. Blue slows down more, causing greater refraction.



Light passing through a diffraction grating is diffracted by differing amounts based on incident wavelength, as described by $\lambda = \frac{d\sin\theta}{n}$. For a grating, longer wavelengths diffract more than shorter wavelengths and deviate from the original path by a greater amount, as shown below.



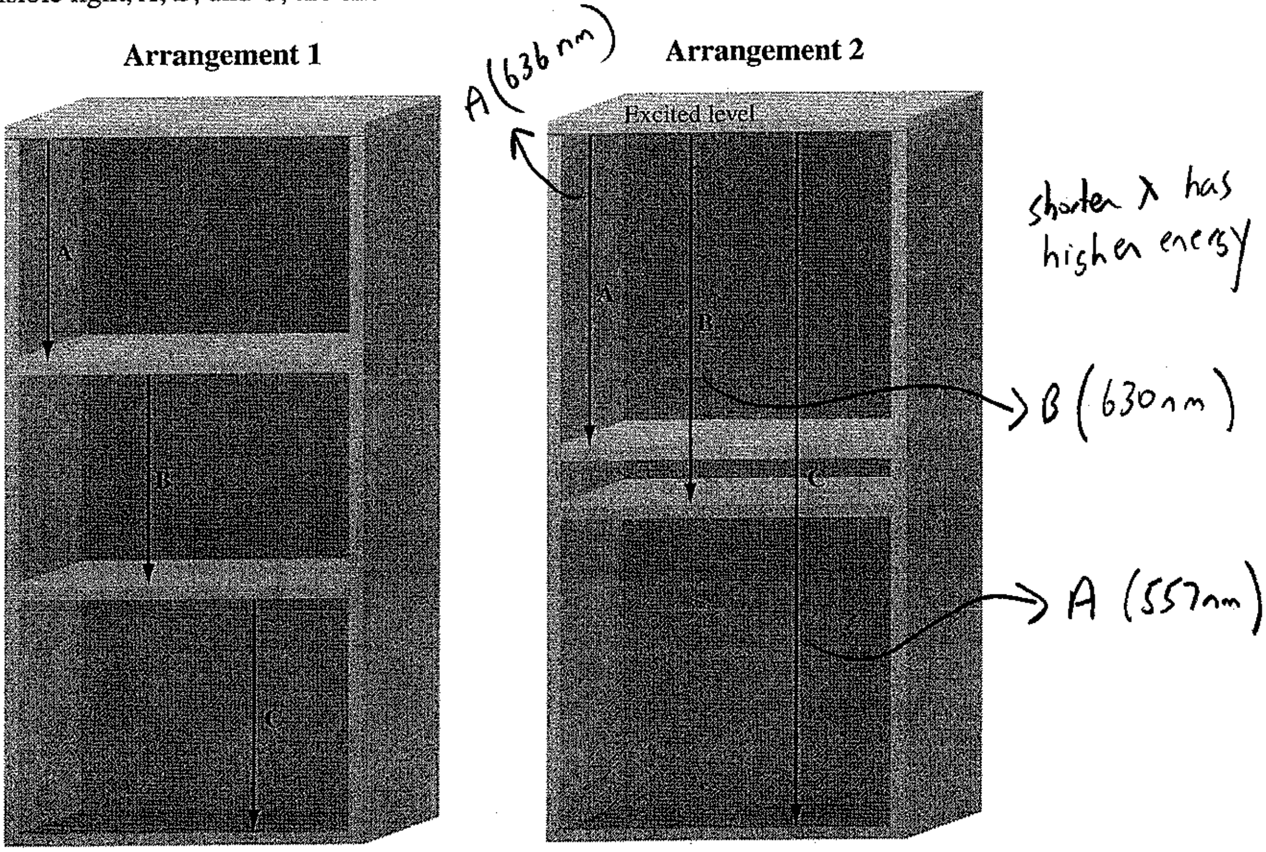
Visible wavelengths are between 400 nm and 700 nm, so for the given spectrum the emission lines that are in the visible range are *A* (557nm), *B* (630 nm) and *C* (636 nm). The other wavelengths are in the infrared section of the spectrum.

The larger the wavelength, the smaller the energy, as describe by $E = \frac{hc}{\lambda}$. So, a photon associated with the 557 nm emission line has the largest energy, followed by a photon associated with the 630 nm emission line, and the photon associated with the 636 nm emission line has the least amount of energy.

10 (cont)

Emission spectra are explained in terms of an atomic model that has electrons in specific stable energy states. Electrons in higher energy states make transitions to lower energy states and emit specific photons. Each transition causes the emission of one photon. Two arrangements of shelves to model the production of the three spectral lines corresponding to visible light, *A*, *B*, and *C*, are shown below

Arrangement 1 **Arrangement 2**



Note to Teachers: The use of the verb *evaluate* is meant to cue the students that they are expected to not only pass a value judgment on this model (good/bad, acceptable/unacceptable, etc.) but to support that judgment with at least one valid argument.

The use of a bookshelf to model electron energy levels could be viewed as acceptable since it attempts to describe the energy of a photon as equivalent to the difference in energy between two stable energy states. Since the shelves are moveable it would also be possible to describe the spectral emissions for other parts of the electromagnetic spectrum or even of other excited atoms.

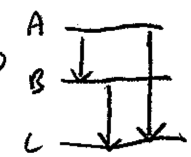
OR

The use of a bookshelf to model electron energy levels could be viewed as unacceptable since it describes electron location (shelf) as a fixed position in space rather than as a statistical probability state. The use of a fixed position (shelf) to describe electron location more closely matches outdated models, such as the Bohr model, than our current model. The ability to move smoothly between one shelf and another shelf also does not match the current concept of a quantum transition, according to which there are locations e⁻ cannot occupy.

either is acceptable; you must support your choice.

Sample response

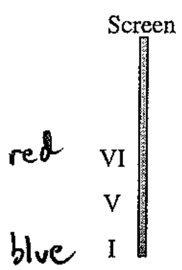
11. Electrical energy is transferred to electrons in the helium atoms, causing the electrons to undergo transitions to higher energy levels. As these electrons undergo transitions to lower energy levels, they emit photons that have energy equal to the difference in energy of the energy levels. These photons constitute the electromagnetic radiation emitted by the discharge tube. Within a collection of atoms, the excited state the atoms reach will vary so that as they return to lower energy states, different wavelengths are emitted. Also, several different paths can be followed as an atom goes to a lower energy state. This would produce a variety of emitted wavelengths. The energy of an emitted photon matches the change in energy of the atom.

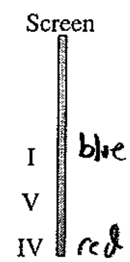


In classical physics, stable electron energy levels are necessary to account for emission spectra because of the requirement that electrons undergoing centripetal acceleration as they orbit the nucleus must continuously emit electromagnetic radiation (EMR). The loss in energy created by the emission of EMR would result in a continuously changing orbit of the electron, eventually leading to the electron colliding with the nucleus. Observations do not provide evidence that this happens, so it became necessary to modify the model of the atom so that the electron is not described as orbiting the nucleus. Early models were modified to predict that there are certain, very specific orbits that were non-radiative (stationary states). Later models describe electrons as being wavelike, and as forming stable, standing wave patterns at certain positions around the atom. Since electrons are no longer described as accelerating particles, the need for continuous emission of EMR is not an issue.

Line position as observed by:

First Group of Students (Prism) **Second Group of Students (Grating)**





When passing through the prism, the red light (line VI) refracts the least because of its longer wavelength. Blue light (line I) refracts the most because of its shorter wavelength. The greater refraction by the blue light causes line I to be projected the furthest from the centre of the screen.

When passing through the diffraction grating, the red line (VI) diffracts the most because of its longer wavelength and blue light diffracts the least. This causes the red line to be produced the furthest from the centre of the screen.

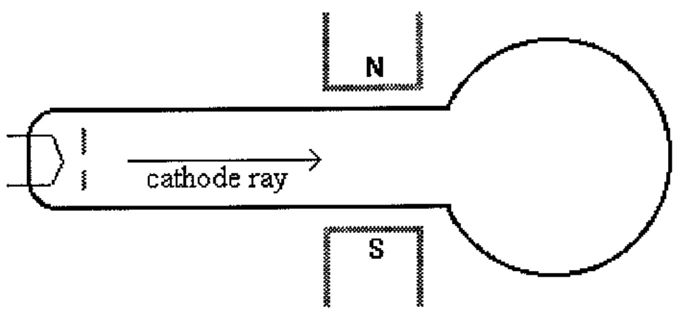
Name: ______________________ Class: __________________ Date: _________ ID: A

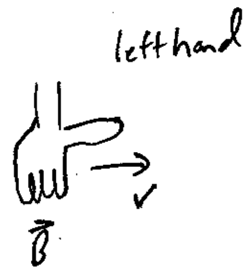
Pre-Test 7. Atomic Physics - Show Work for mathematical questions

Multiple Choice
Identify the choice that best completes the statement or answers the question.

A 1. Which of the following is a characteristic of cathode rays? 3rd left hand rule will determine Fm direction.
- (a.) Cathode rays are affected by magnetic fields.
- b. Cathode rays are positively charged particles.
- c. The nature of the cathode determines the nature of cathode rays.
- d. The direction of propagation of cathode rays is toward the cathode.

D 2. The sketch below shows a beam of cathode rays travelling into a magnetic field.





The cathode rays are deflected
- a. toward S
- b. toward N
- c. into the page
- (d.) out of the page

C 3. J.J. Thomson found that cathode rays are deflected by
- a. electric but not magnetic fields
- b. magnetic but not electric fields
- (c.) both electric and magnetic fields
- d. neither electric nor magnetic fields

B 4. Thomson's contribution to atomic theory was his discovery of the
- a. proton
- (b.) electron
- c. neutron
- d. nucleus

D 5. What is the charge-to-mass ratio of a particle travelling at 2.29×10^6 m/s perpendicularly to a magnetic field of intensity 0.200 T if its circular path has a radius of 12.0 cm?
- a. 5.50×10^4 C/kg
- b. 1.37×10^6 C/kg
- c. 3.82×10^6 C/kg
- (d.) 9.54×10^7 C/kg

$F_m = F_c$

$qvB = \frac{mv^2}{r}$

$\frac{q}{m} = \frac{v}{Br}$

$\frac{q}{m} = \frac{2.29 \times 10^6}{(0.200)(12 \times 10^{-2})} = 9.54 \times 10^7 \frac{C}{kg}$

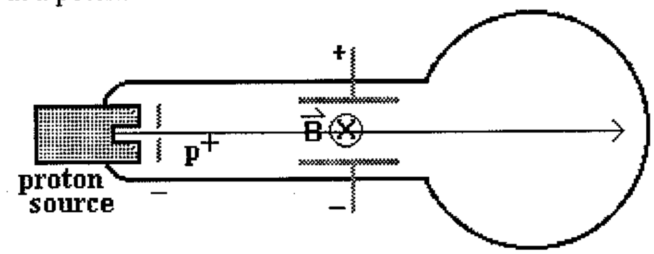
1

Name: ______________________ ID: A

0

6. The sketch below shows a proton travelling in a straight line through uniform perpendicular electric and magnetic fields. The electric field exists between two charged plates that are 2.5 cm apart and are maintained at a potential difference of 275 V.

undeflected



$F_{el} = F_m$

$q|\vec{E}| = q v B_\perp$

$\frac{\text{Volts}}{d} = \vec{v} B_\perp$

$\frac{275}{2.5 \times 10^{-2}} = \vec{v} \cdot 2.2 \times 10^{-3}$

5.0×10^{6} m/s $= \vec{v}$

If the magnetic field is 2.2×10^{-3} T, the speed of the proton is:

a. 1.1×10^4 m/s
b. 5.0×10^4 m/s
c. 1.3×10^5 m/s
d. 5.0×10^6 m/s

C 7. An electron passes without deflection through perpendicular electric and magnetic fields of 10.0 kN/C and 11 mT respectively. The speed of the electron is:

a. 1.1×10^{-6} m/s
b. 2.1×10^{-5} m/s
c. 9.1×10^5 m/s
d. 4.8×10^6 m/s

$F_{el} = F_m$

$\vec{v} = \frac{|E|}{B} = \frac{10 \times 10^3 \text{ N/C}}{11 \times 10^{-3} \text{ T}}$

$\vec{v} = 9.1 \times 10^5$ m/s

C 8. J.J. Thomson proposed an atomic model that described the atom as a sphere

a. of positive electricity about which an equal amount of negative charges orbits
b. of positively charged and neutral particles about which negative charges orbit
c. of positive electricity in which an equal amount of negative charge is distributed
d. with a very dense positively charged nucleus surrounded by orbiting negative charges

A 9. The key significance of Rutherford's scattering experiment is the discovery of the

a. nucleus
b. electron
c. elementary charge
d. quantization of charge

C 10. The most surprising evidence from Rutherford's experiment that disproved Thomson's model was that:

a. the alpha particles were able to pass through the gold foil
b. most of the alpha particles were deflected by less than one degree
c. a few alpha particles were scattered through very large angles
d. the scattering was less random than expected

C 11. Several gaseous elements and vapours of solid elements are heated. The emitted light is studied with a spectroscope. Which statement is correct?

a. The light from each element consists of a broad and continuous range of wavelengths.
b. Vapours of solid elements produce spectra that consist of a continuous range of wavelengths.
c. The light from each element consists of bright spectral lines that are characteristic of the element.
d. Some of the bright lines in the spectrum of an element are exactly the same as those in every other element's spectrum.

C 12. An important technological application of line spectra is

a. chemical analysis
b. producing new chemicals
c. household light bulbs
d. explaining atomic structure

each chemical emits a characteristic emission spectrum

13. The evidence that emission and absorption spectra exist was used by Bohr to create the concept of
   a. the nuclear model of the atom
   b. new lighting technologies
   c. quantized electric charge
   d. quantized energy levels of electrons

14. Bohr explained the phenomenon of the hydrogen spectrum by hypothesizing that
   a. electrons have angular momenta corresponding to the energies of light observed in the spectrum
   b. discrete frequencies of light are emitted when a transition between two allowable energy states of the atom takes place
   c. the wavelengths of light observed in the spectrum correspond to the radii of the allowable orbitals of the atom
   d. the electric influence of the electrons interacting with the magnetic influence of the nucleus produces electromagnetic waves corresponding to the frequencies of the observed spectrum

15. An electron in a stationary state will produce
   a. no spectrum
   b. an emission spectrum
   c. an absorption spectrum
   d. a continuous spectrum

16. An electron drops from the fifth energy level ($E_5 = -8.7 \times 10^{-20}$ J) to the second energy level ($E_2 = -5.4 \times 10^{-19}$ J) within an excited hydrogen atom. The frequency of the emitted photon is:
   a. 4.8×10^{14} Hz
   b. 6.8×10^{14} Hz
   c. 8.2×10^{14} Hz
   d. 9.6×10^{14} Hz

17. What is the minimum frequency of a photon that would be required to ionize a hydrogen atom?
   a. 4.87×10^{-35} Hz
   b. 3.04×10^{-16} Hz
   c. 3.29×10^{15} Hz
   d. 2.05×10^{34} Hz

18. An electron with kinetic energy 4.9 eV collides with an atom in the ground state. The second energy level of the atom is 4.1 eV above its ground state. If, after collision, the atom is in its first excited state, the final energy of the incident electron is:
   a. 0.4 eV
   b. 0.8 eV
   c. 4.1 eV
   d. 9.0 eV

19. The first four energy levels for an atom are:
   $E_1 = -8.57$ eV $E_2 = -2.14$ eV $E_3 = -0.95$ eV $E_4 = -0.54$ eV
   An electron with a kinetic energy of 7.74 eV collides with an atom in its ground state. After the collision, the atom is in an excited state and the electron is scattered. The kinetic energy of the scattered electron could be
   a. 16.31 eV
   b. 0.83 eV
   c. 0.29 eV
   d. 0.12 eV

20. Quantum mechanics is a theory of the nature of matter that provides a
   a. clear picture of any atom
   b. highly visual physical model of the atom
   c. mathematical representation that can be used to predict interactions among particles, fields, and radiation
   d. means of calculating the position and physical condition of any individual electron in any individual atom

C 21. What is a major difficulty in understanding quantum mechanics?
a. It is highly geometric.
b. It does not improve on Newtonian mechanics.
c. It is almost entirely mathematical, and difficult to visualize.
d. It states that certain materials possess neither wave nor particle properties.

B 22. An electron accelerates from rest through a potential difference of 2.00 kV. What is its de Broglie wavelength at the end of its acceleration?
a. 1.04×10^{-18} m
b. 2.75×10^{-11} m
c. 3.88×10^{-11} m
d. 8.69×10^{-10} m

1) find v
$qV = \frac{1}{2}mv^2$
$(1.6\times10^{-19})(2000) = \frac{1}{2}9.11\times10^{-31}v^2$
2.65×10^7 m/s → v
2) $\lambda = \frac{h}{mv}$
$\lambda = \frac{h}{9.11\times10^{-31} \cdot 2.65\times10^7}$

C 23. Electron microscope technology is possible because
a. electrons exhibit particle properties and penetrate matter.
b. electrons exhibit particle properties and can ionize matter.
c. electrons exhibit wave properties and can be focused.
d. electrons exhibit wave and particle characteristics, and they ionize and penetrate matter.

A 24. The wavelength of a matter wave can be increased by
a. decreasing the speed of the matter.
b. increasing the speed of the matter.
c. increasing the mass of the matter.
d. decreasing the frequency of the matter.

$\lambda = \frac{h}{mv}$
$\lambda \propto \frac{1}{v}$

C 25. The best evidence for matter waves is/are
a. polarization.
b. ionization of matter.
c. interference patterns.
d. mathematical models.

called quantum interference

C 26. The double-slit experiment showed that
a. only light could diffract and interfere.
b. only matter could diffract and interfere.
c. both light and matter could diffract and interfere.
d. both light and matter could diffract but not interfere.

– both light and matter have a duel nature (particle and wave)

Numeric Response

27. An electron accelerated to $\frac{1}{8}$c experiences a radius of deflection of 6.5 mm in a magnetic field of 32 mT. The charge-to-mass ratio for the electron is ***a.b*** × ***10^cd*** C/kg. The values of ***a***, ***b***, ***c***, and ***d*** are 1, 8, 1, and 1. (Record all **four digits** of your answer on the answer sheet.)

$F_m = F_c$
$qvB = \frac{mv^2}{r}$
$\frac{q}{m} = \frac{v}{Br} = \frac{.125\times3\times10^8}{32\times10^{-3}\cdot6.5\times10^{-3}} = 1.8\times10^{11}$ C/kg