LIFEPAC®

SCIENCE

STUDENT BOOK

12th Grade | Unit 9

Alpha Omega Publications

SCIENCE 1209

ATOMIC AND NUCLEAR PHYSICS

LIFEPAC Test is located in the center of the booklet. Please remove before starting the unit.

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Alpha Omega PUBLICATIONS

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Atomic and Nuclear Physics

Introduction

You are about to begin the study of modern physics, the physics of very small objects. You will learn more about how atoms and their subparts interact. The laws of physics that you have already learned will be used, but you will notice that at times some new concepts will be considered.

Objectives

Read these objectives. The objectives tell you what you will be able to do when you have successfully completed this LIFEPAC®. When you have finished this LIFEPAC, you should be able to:

1. Explain when wave theory is applicable and when quantum theory is applicable.
2. Calculate the energy of photoelectrons and x-rays.
3. Explain de Broglie waves.
4. State and apply the uncertainty principle.
5. Define emission spectra and absorption spectra.
6. Define line spectra and continuous spectra.
7. Describe the Bohr model of the hydrogen atom.
8. Define nucleon and isotopes.
9. Explain mass defect in terms of mass-energy equivalent.
10. Explain how the binding energy curve shows that fission and fusion can release energy.
11. Explain the concept of half-life.
12. Explain how alpha and beta decay can stabilize a nucleus.
13. Describe fission reaction and fusion reaction.
14. Explain a chain reaction and nuclear energy.

A FORMULA page in the back of this LIFEPAC contains formulas and constants that may be used for problem-solving, both on activities and on tests. The page can be removed for easy reference.

Survey the LIFEPAC. Ask yourself some questions about this study and write your questions here.

1. QUANTUM THEORY

For many centuries, the primary concern of physics was to describe the behavior of large objects. Newtonian mechanics describes the behavior of matter influenced by gravitational fields or by electromagnetic interactions. Newtonian physics had been successful; so successful, in fact, that most physicists believed they were approaching the ultimate description of nature. They thought that in just a matter of time they would be able to work out the details of a perfect, ordered world. Many believed that the future work of physics would be essentially just measuring the last decimal place.

Problems with this neat and supposedly complete theoretical description began to arise about the end of the nineteenth century. More precise experiments opened a whole new world to the physicist who was beginning to investigate the properties of very small particles. The behavior of these microscopic systems could not be explained in terms of the classical physics and Newtonian mechanics, which had been the physicists' stock and trade up to this point.

In classical physics, the physicist had explained the behavior of objects in terms of direct and compelling deductions from a well defined set of experiments. Attempts to do the same from new observations were not successful. The new physics, or *quantum physics*, was too abstract to make deductive explanations possible. The main reasons were twofold: The basic constructs of this quantum theory were removed from everyday experience, and the microscopic particles could not be observed directly.

Section Objectives

Review these objectives. When you have completed this section, you should be able to:

1. Explain when wave theory is applicable and when quantum theory is applicable.
2. Calculate the energy of photoelectrons and x-rays.
3. Explain de Broglie waves.
4. State and apply the uncertainty principle.
5. Define emission spectra and absorption spectra.
6. Define line spectra and continuous spectra.
7. Describe the Bohr model of the hydrogen atom.

Vocabulary

Study these words to enhance your learning success in this section.

absorption spectrum	**alpha particle**	**continuous spectrum**
de Broglie wave	**electron volt**	**emission spectrum**
energy levels	**excited atom**	**ground state**
line spectrum	**photoelectric effect**	**photon**
proton	**quanta**	**quantum number**
radiation	**uncertainty principle**	**x-ray**

Note: *All vocabulary words in this LIFEPAC appear in* **boldface** *print the first time they are used. If you are not sure of the meaning when you are reading, study the definitions given.*

ELECTROMAGNETIC RADIATION

The wave theory of light was well recognized by the end of the nineteenth century. Experimental work was being conducted in which both light rays and high speed electrons were allowed to strike a metal surface. The results of these experiments could not be explained by existing theory. As a result, a new theory was developed, called the *quantum theory*. At the time, physicists did not fully realize what was happening; but modern physics had been born.

Photoelectric effect. During the late 1800s, several experiments disclosed that electrons were emitted when light fell on a metal plate. This phenomenon is the **photoelectric effect**. At first, no one was surprised: light waves were known to carry energy; some of this energy, therefore, could somehow be absorbed by electrons to give them enough kinetic energy to escape from the metal surface.

Soon several problems developed: *First*, the energy of the photoelectrons was not related to the *intensity* of the light. When the light was made brighter, more electrons were emitted; but they all had the same average energy as those emitted by dim light. *Second*, the energy of the photoelectrons was related to the *frequency* of the light. If the frequency was below a certain value, no electrons were emitted even if the light was intense. Conversely, if the frequency was above the value, electrons were emitted even in very dim light.

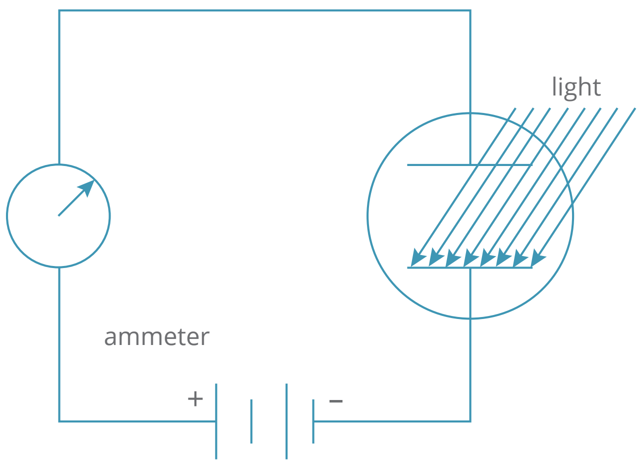
Photoelectrons emitted by any given frequency were observed to have energy that ranged from zero to some maximum value. If the frequency of the light was increased, the maximum electron energy increased. In other words, a faint blue light produced electrons with higher energy than did a bright red light even though the bright red light produced more electrons. The relationship between KE_{max}, the maximum photoelectron energy, and the frequency of the incident light can be stated:

maximum photoelectron energy = h(frequency − frequency$_0$)

$$KE_{max} = h(f - f_0).$$

The symbol f represents the frequency of incident light. The value of h was always the same value, but f_0 changed for each metal.

An explanation of this phenomenon was given in 1905 by Albert Einstein. He used a result of earlier work by the German physicist Max Planck, who described the **radiation** emitted by a glowing



object. Planck could get his theory to work if he assumed that the light was emitted in little “lumps” of energy. He called these little bursts of energy **quanta** and showed that they had energy of

$$E = hf,$$

where f is the frequency and h is a constant known as *Planck’s constant*. The value of Planck’s constant h is given as

$$h = 6.63 \cdot 10^{-34} \text{ joule} \cdot \text{sec}.$$

Few physicists really believed in Planck’s quanta, but Einstein pointed out that the photoelectric effect was experimental verification of Planck’s equation. He suggested that the photoelectric equation be rewritten:

$$hf = KE_{max} + hf_0,$$

and be stated:

> quantum (incident photon) energy = maximum electron energy + energy required to eject an electron from the metal surface.

A large portion of the photoelectron population will have less than maximum energy for the following reasons:

1. The photon (the quantum of incident light) may have shared its energy with more than one electron.
2. The electron may have lost part of its energy before it got out of the metal.

The energy of photons is so small that the joule is cumbersome. A unit of energy suited to the atomic scale is the **electron volt**. One electron volt is the energy change realized by an electron moving through a potential change of one volt. Numerically,

$$1 \text{ eV} = 1.6 \cdot 10^{-19} \text{ joules}$$

LIFEPACs 1204 and 1205 dealt with diffraction and interference. The observed phenomena could be explained in terms of the wave theory of light. Now you have seen an argument that light behaves like a series of packets of energy, called *photons*, or *quanta*, each **photon** small enough to interact with a single electron. The wave theory cannot explain the photoelectric effect and the quantum theory cannot explain interference and diffraction. Which is the correct theory? Many times before in physics, one theory has been replaced by a new theory; but this apparent conflict was the first time that two different theories were needed to describe a phenomenon. Developing a model for light is a situation in which science must acknowledge that nature is not an "open book" to man. These two theories are complementary: One is correct in some experiments, but the other theory must be used in others.

Interestingly, light can exhibit either a wave or a particle nature, but never exhibits both in any single situation. Since we cannot reconcile the two descriptive models, we have no choice but to accept them both.

Answer these questions.

1.1 What is the photoelectric effect?

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1.2 Why do photoelectrons have a maximum energy?

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1.3 Why does faint light not appear as a series of flashes?

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1.4 Why can the photoelectric effect not be explained without quantum theory?

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Complete these sentences.

1.5 The phenomenon that describes the emission of electrons from a metal surface when light shines on it is the ____ .

1.6 The maximum energy of photoelectrons a. __________________ with frequency and b. __________________ with increasing intensity of the light. (increases, decreases, remains constant)

1.7 Photon energy is proportional to ____________________ .

1.8 Photons are also known as ____________________ .

Solve these problems.

1.9 A yellow lamp emits light with a wavelength of $6 \cdot 10^{-7}$ m.

a. Write the common value for the speed of light, in meters per second.

b. Calculate the frequency of the yellow light from the equation given in Science LIFEPAC 1204.

c. Use Planck's equation to calculate the energy of a single photon with the given wavelength.

d. How many such photons are required to produce 10 joules?

1.10 A 10,000 watt radio station transmits at 880 kHz.

a. Determine the number of joules transmitted per second.

b. Calculate the energy of a single photon at the transmitted frequency.

c. Calculate the number of photons that are emitted per second.

1.11 Light with a wavelength of $5 \cdot 10^{-7}$ m strikes a surface that requires 2 eV to eject an electron.

a. Calculate the frequency of the given wave.

b. Calculate the energy, in joules, of one incident photon at this frequency.

c. Calculate the energy, in electron volts, of one incident photon.

d. Calculate the maximum *KE*, in electron volts, of the emitted photoelectron.

1.12 Photoelectrons with a maximum speed of $7 \cdot 10^5$ $^{m}/_{sec}$ are ejected from a surface in the presence of light with a frequency of $8 \cdot 10^{14}$ Hz.

a. If the mass of an electron is $9.1 \cdot 10^{-31}$ kg, calculate the maximum kinetic energy of a single electron, in joules.

b. Calculate, in joules, the energy of incident photons.

c. Calculate the energy required to eject photoelectrons from the surface.

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