Bohr's Model of the Hydrogen Atom

Niels Bohr in 1913 when he presented a new model of the hydrogen atom that circumvented the difficulties of Rutherford's planetary model. Bohr applied Planck's ideas of quantized energy levels to Rutherford's orbiting atomic electrons.

Bohr's theory was historically important to the development of quantum physics, and it appeared to explain the spectral line series described by Equations mentioned previously.

Bohr combined ideas from Planck's original quantum theory, Einstein's concept of the photon, Rutherford's planetary model of the atom, and Newtonian mechanics to arrive at a semi-classical model based on some revolutionary ideas. **The postulates of the Bohr Theory as it applies to the hydrogen atom are as follows:**

1. The electron moves in circular orbits around the proton under the influence of the electric force of attraction as shown in Figure 6.

2. Only certain electron orbits are stable. When in one of these stationary states, as Bohr called them, the electron does not emit energy in the form of radiation, even though it is accelerating. Hence, the total energy of the atom remains constant and classical mechanics can be used to describe the electron's motion. Bohr's model claims that the centripetally accelerated electron does not continuously emit radiation, losing energy and eventually spiraling into the nucleus, as predicted by classical physics in the form of Rutherford's planetary model.

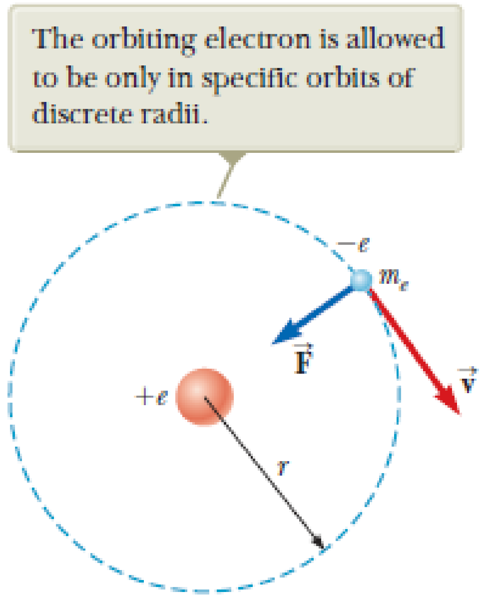


Figure 6 diagram representing Bohr's model of the hydrogen atom

3. The atom emits radiation when the electron makes a transition from a more energetic initial stationary state to a lower-energy stationary state.

This transition cannot be visualized or treated classically. In particular, the frequency f of the photon emitted in the transition is related to the change in the atom's energy and is not equal to the frequency of the electron's orbital motion. The frequency of the emitted radiation is found from the energy-conservation expression

$$E_i - E_f = hf \qquad \text{(eq. 1)}$$

where E_i is the energy of the initial state, E_f is the energy of the final state, and $E_i > E_f$.

4. The size of an allowed electron orbit is determined by a condition imposed on the electron's orbital angular momentum: the allowed orbits are those for which the electron's orbital angular momentum about the nucleus is quantized and equal to an integral multiple of $\hbar = h/2\pi$

$$m_e v r = n\hbar \qquad \textbf{(eq. 2)}$$

where **m** is the electron mass , **v** is the electron speed in its orbit and **r** is the orbital radius .

The total energy of the atom, which consists of the electron's kinetic energy and the system's potential energy, is

$$E = K + U = \tfrac{1}{2} m_e v^2 - k_e \frac{e^2}{r} \qquad \textbf{(eq.3)}$$

The electron is modeled as a particle in uniform circular motion, so the electric force $k_e e^2/r^2$

Exerted on the electron must equal the products of its mass and its centripetal acceleration $a_c = v^2/r$

The orbit with the smallest radius, called the Bohr radius a0, corresponds to n = 1 and has the value

$$a_0 = \frac{\hbar^2}{m_e k_e e^2} = 0.052\,9 \text{ nm} \qquad \textbf{(eq. 4) Bohr radius}$$

Substituting Equation**11** into Equation **10** gives a general expression for the radius of any orbit in the hydrogen atom:

$$r_n = n^2 a_0 = n^2 (0.052\,9 \text{ nm}) \qquad n = 1, 2, 3, \ldots$$

(eq. 15) Radii of Bohr orbits in hydrogen.

Blackbody Radiation and Planck's Hypothesis

An object at any temperature emits electromagnetic waves in the form of **thermal radiation** from its surface. The characteristics of this radiation depend on the temperature and properties of the object's surface. Careful study shows that the radiation consists of a continuous distribution of wavelengths from all portions of the electromagnetic spectrum. If the object is at room temperature,

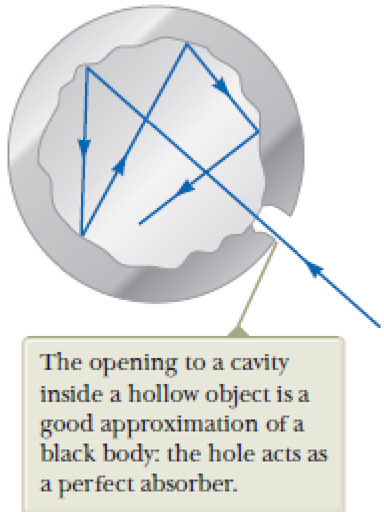
the wavelengths of thermal radiation are mainly in the infrared region and hence the radiation is not detected by the human eye. As the surface temperature of the object increases, the object eventually begins to glow visibly red, like the coils.

of a toaster. At sufficiently high temperatures, the glowing object appears white, as in the hot tungsten filament of an incandescent light bulb.

From a classical viewpoint, thermal radiation originates from accelerated.

charged particles in the atoms near the surface of the object; those charged particles emit radiation much as small antennas do. The thermally agitated particles can have a distribution of energies, which accounts for the continuous spectrum of radiation emitted by the object. The basic problem was in understanding the observed distribution of wavelengths in the radiation emitted by a black body; a **black body** is an ideal system that absorbs all radiation incident on it. The electromagnetic radiation emitted by the black body is called **blackbody radiation.**

A good approximation of a black body is a small hole leading to the inside of a hollow object as shown in **Figure 7**. Any radiation incident on the hole from outside the cavity enters the hole and is reflected a number of times on the interior walls of the cavity; hence, the hole acts as a perfect absorber. The nature of the radiation leaving the cavity through the hole depends only on the temperature of the cavity walls and not on the material of which the walls are made. The spaces between lumps of hot charcoal emit light that is very much like blackbody radiation.



Figure(7) A physical model of a black body.

The radiation emitted by oscillators in the cavity walls experiences boundary conditions. As the radiation reflects from the cavity's walls, standing electromagnetic waves are established within the three-dimensional interior of the cavity.

Many standing-wave modes are possible, and the distribution of the energy in the cavity among these modes determines the wavelength distribution of the radiation leaving the cavity through the hole.

The wavelength distribution of radiation from cavities was studied experimentally in the late 19th century. Active Figure 40.3 shows how the intensity of blackbody radiation varies with temperature and wavelength. The following two consistent experimental findings were seen as especially significant:

1. The total power of the emitted radiation increases with temperature. where we introduced Stefan's law:

$$P = \sigma A e T^4 \qquad \textbf{(eq.13) Stefan's law}$$

where P is the power in watts radiated at all wavelengths from the surface of an object, $\sigma = 5.670*10^{8}\ W/m^2$. K^4 is the Stefan–Boltzmann constant, A is the surface area of the object in square meters, e is the emissivity of the surface, and T is the surface temperature in kelvins. For a black body, the emissivity is e = 1 exactly.

2. The peak of the wavelength distribution shifts to shorter wavelengths as the temperature increases. This behavior is described by the following relationship, called Wien's displacement law:

$$\lambda_{max}\, T = 2.898*10^{-3}\ m\,.\,K \qquad \textbf{(eq.14) Wiens displacement law}$$

where λ_{max} is the wavelength at which the curve peaks and T is the absolute temperature of the surface of the object emitting the radiation. The wavelength at the curve's peak is inversely proportional to the absolute temperature; that is, as the temperature increases, the peak is "displaced" to shorter wavelengths (Fig. 8).

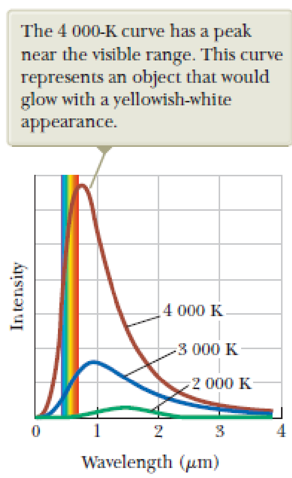


Figure (8) Intensity of blackbody radiation versus wavelength at three temperatures. The visible range of wavelengths is between 0.4 mm and 0.7 mm. At approximately 6 000 K, the peak is in the center of the visible wavelengths and the object appears white.

At room temperature, the object does not appear to glow because the peak is in the infrared region of the electromagnetic spectrum.

At higher temperatures, it glows red because the peak is in the near infrared with some radiation at the red end of the visible spectrum, and at still higher temperatures, it glows white because the peak is in the visible so that all colors are emitted.