SECTION 15

A Model for the Universe (5)
Quanta and the Atom

The development until the present section has been the presentation of this Universal Physics concept of the universe and the demonstration that it accounts for the various established physical laws and effects: Newton's Laws of Motion, Coulomb's Law, relativity, Ampere's Law, Maxwell's Equations, and the associated fundamental physical entities and effects of force, mass, motion, charge and fields. The discussion has treated the fundamental forces, particles and motions of the universe showing that the concepts of this Universal Physics are the underlying basis for them and that this Universal Physics unifies and extends them.

Now, however, the development has come to a point where there are mere hypotheses of various qualities and validities rather than "established physical laws". The presentation can no longer be in terms of correlating this Universal Physics to physical laws, rather, the correlation must now be directly to experimental data, to the underlying natural behavior, observations of which have led to the current hypotheses. The hypotheses are not sufficiently reliable, but are, rather, at least potentially suspect. They may be correct, partially so or entirely wrong. In any case, it is natural reality as known through experimental data that must be satisfactorily explained.

The problem with the hypotheses of 20th Century physics is as follows. On the one hand:

> All forms of E-M field, or E-M radiation, exhibit behavior indicating that the phenomena are wave in nature. Electromagnetic field and Maxwell's Equations depend on the wave nature of E-M radiation.

But on the other hand:

> In several situations E-M field and radiation behave in a fashion that would seem to be that of particles, not waves, behavior that appears to require them to have a particle nature if the behavior is to be explained.

Given this dilemma, 20th Century physics takes the position that sometimes the behavior is as of waves, sometimes it is as of particles, and the two aspects are not presently reconcilable. They must simply be accepted, at least pending new progress.

The wave aspect of E-M phenomena is too well established to be rejected. This is because of the success of Maxwell's theory and the many instances of behavior requiring a wave nature if the behavior is to be explained: frequency, wavelength, polarization, interference and diffraction. Consequently, even the particle aspect is considered by 20th Century physics as being "packets" of waves. But the contradictions in the two aspects are still unacceptable.

A wave in free space must spread out as it propagates, but the "wave packets" must be considered as staying together like a particle. The E-M wave front is continuous, but a front of propagating particles involves the particles' moving radially from the source with the distance between particles increasing with distance from the source and nothing in the spaces between. E-M radiation is produced by acceleration of charge and must produce propagation that is spatially symmetrical to the charge's motion, but the particle theory requires that the radiation travel away from the accelerated charge as a particle in some specific direction without symmetry. The next particle may be in another direction, the next in a third, and so on, so that a large number of radiated particles exhibit a dispersion pattern like that of the wave field, but this still is behavior that is inconsistent with the wave aspect.

When waves encounter an impenetrable barrier with an aperture in it, the portion of the waves that encounter the aperture and pass through propagate from its far side as if it were a new source of radiation, that is in all directions. Particles in such a circumstance, that is those particles which encounter the aperture instead of the barrier, should simply continue traveling in straight paths. If the particles (because said to be packets of waves) were to propagate in the fashion of waves from the aperture they would either have changed from particle to wave, or have each subdivided into numerous particles, or have cooperated by leaving the aperture in random directions simulating the behavior of a wave field.

In order to develop how the concepts of this Universal Physics resolve this dilemma into a simple unified reality it is first necessary to review the data that led to the particle theory of E-M radiation. The particles of E-M radiation are called *photons*. A photon is also referred to as a quantum of energy, and the particle aspect of light led to the quantum mechanical view of the atom. But while quantum mechanics is a way of looking at atomic level phenomena and has produced useful results, it is largely inaccurate as a conception of reality.

Quantum mechanics does not even profess to be a type of representational model of matter; rather, it is simply a mathematical system of treatment of the data that provides some valid solutions to problems. Unfortunately, the non-model caveat has tended to be forgotten and thinking has tended to conceive of reality in quantum mechanical terms. The problem with that is that it is, again just as pre-Copernican astronomy (geocentric astronomy), accurate up to a point as a tool of analysis and useful to that extent, but fundamentally incorrect as a description of nature and, therefore, an ultimate hindrance to further progress and understanding of reality.

Four different natural phenomena, in apparent conflict with the wave aspect of E-M field, led to the development of the quantum theory:

- The E-M radiation from a material body due to its heat energy (called *black body* radiation),

- The *photoelectric effect*,

- *Line spectra* of gases and the related *electron orbital model* of the atom, and
- The discovery of *matter waves* by diffraction of electrons.

Each of these is discussed in the following analysis.

BLACK BODY RADIATION

The amount of energy radiated at various wavelengths from a material body varies with the temperature of the body (e.g. a piece of metal as heated hotter and hotter changes in the apparent color of its glow from dull red through orange to bright white). Experimental observations of this consistently show a characteristic pattern as in Figure 15-1, below: low energy magnitude at small wavelength, followed by a peak around a wavelength that depends on the temperature of the radiating body, further followed by a tapering off as wavelength further increases.

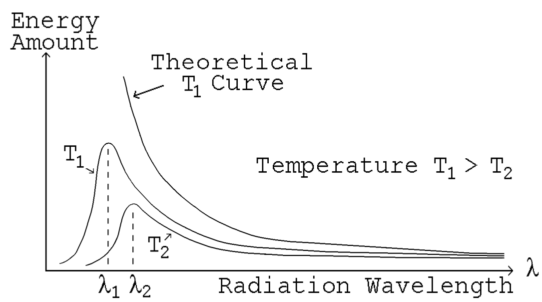


Figure 15-1

If a theoretical curve is calculated based on E-M wave theory and compared to the measured actual results a discrepancy appears. The theoretical curve increases without limit as wavelength becomes smaller instead of peaking and then declining toward zero.

This conflict of theoretical and actual behavior was resolved by Planck. He found that if the theoretical curve was derived upon the supposition that the radiant energy was given off in minute bursts rather than as continuous waves, and that each minute burst has the energy of equation 15-1, below,

$$W = h \cdot f \quad (15\text{-}1)$$

then the theoretical curve matched the actual curve for the given temperature. In equation 15-1, f is the frequency of the radiation and h is a (then new) universal constant, subsequently named *Planck's constant*. The above equation and Planck's constant were introduced in the earlier section *12 - A Model for the Universe (2) - Mass and Matter*.

THE PHOTOELECTRIC EFFECT

Under suitable circumstances, it is found that when light or other E-M radiation of sufficiently high frequency shines on or encounters a material substance then electrons are given off by the substance. This *photoelectric effect* is the operating principle of television cameras, xerographic copiers, etc. The normal expectation would be that one would have to wait a shorter or longer time, depending on the intensity of the light, while it delivers enough energy to free the electrons, a heating up period so to speak. On that basis any E-M radiation should produce some electrons from the substance that it encounters if given enough time.

But, that mode of behavior is not the case. Experimental observations show that there is no heating up time, no apparent energy accumulation. Electrons are liberated by the incident light immediately if they are to be liberated at all. There is a threshold frequency, however, below which the light never releases electrons, at and above which electrons are always released, and at and above which the rate at which electrons are given off depends on the light intensity. The threshold frequency is different for different substances on which the light is shined. Furthermore, the electrons are given off with various individual energies, but the maximum energy of the released electrons depends directly on the light frequency. Figure 15-2, below, depicts this photoelectric effect behavior for different substances.

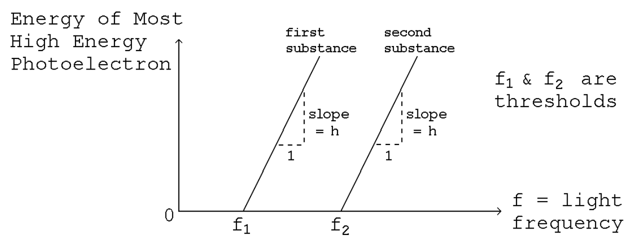


Figure 15-2

The slope of all such lines turns out to be the same, as depicted above. (The slope is the amount the line rises per unit horizontal change.) Furthermore, the slope turns out to have the same value as Planck's constant, h, the constant that Planck found necessary to explain black body radiation.

Einstein explained this behavior by postulating, similarly to Planck's assumption for black body radiation, that the light travels in packets of energy each containing the energy of equation 15-1, above, $W = h \cdot f$. These packets of light energy were given the name *photons*. Einstein's hypothesis was that if a photon that is part of the incident light and that encounters an electron in the substance has enough energy W due to its frequency f so that the photon energy is greater than the energy binding the electron into the substance, then the electron will be released. Photons at frequencies below that threshold would not have enough energy to free an encountered electron. A photon of energy greater than the threshold would not only release the electron but would impart its excess energy to the electron as kinetic energy of motion. The rate at which electrons are released would depend on the rate of photons with time, which corresponds to the intensity of the light.

This all would appear to be quite strong support for the photon-quantum theory, and there is more.

LINE SPECTRA AND THE ATOMIC ORBITAL ELECTRON MODEL

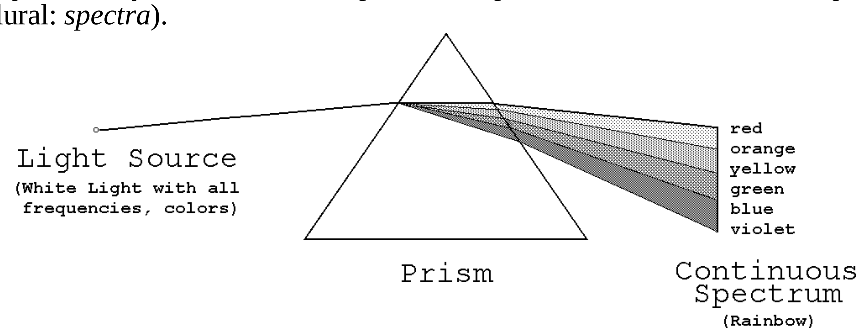
Experiments involving the passing of charged particles through solid matter (Rutherford's experiments passing positive particles called "alpha particles" through metal foil) show that atoms must consist of a quite small nucleus, which contains all of the positive charge of the atom and almost all of its mass, with the large remainder of the volume of the atom being empty space in which the electrons are found. The only way for the negatively charged electrons to exist in such a context without being drawn into the positive nucleus by the Coulomb attraction is for each electron to move around the nucleus in an orbit such that the Coulomb attraction toward the nucleus is just correct to curve the electron into its orbital path (the "centrifugal force" offsets the Coulomb attraction). Thus arises the "planetary" model of the atom.

In this model as so far presented, the electrons could be in any of a continuum of orbits from close in to the nucleus to far out from it, the orbital speed being for any orbit the correct amount to balance the Coulomb attraction at that radial distance from the nucleus. But such electrons are continuously accelerated into their curved paths and classical physics expects that an accelerated electron should emit E-M radiation. Since emitted radiation carries energy the orbital electrons should lose energy to the radiation and be unable to maintain the required orbital speed. Thus the electrons should be expected to emit E-M radiation and fall toward the nucleus rather than remaining in orbital stability.

That classically expected radiation does not in general occur in atoms, however (and if it did occur atoms could not exist). Rather, there is a series of discrete stable orbits in which the electron can remain without automatically radiating. This fortunate (for us) behavior requires an explanation, which will be developed shortly. 20th Century physics has no explanation for this. The stability of the orbital electrons in their orbits is simply taken as a postulate in 20th Century physics, no more explained than is field explained.

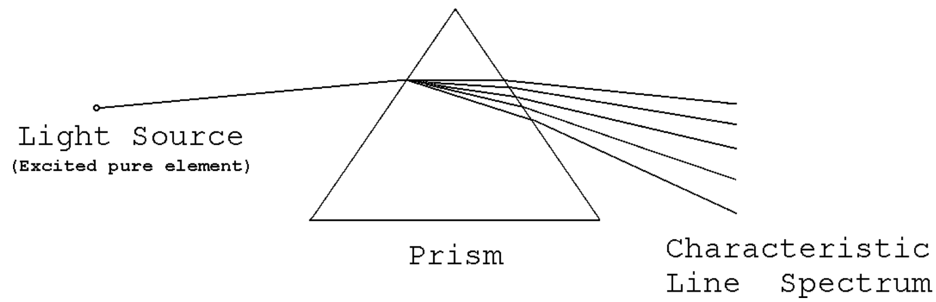
But atomic orbital electrons do sometimes give off some radiation. However, it is not a continuum over a range of frequencies as would be expected classically if the electrons were to radiate continuously, lose energy and spiral inward toward the nucleus. Rather, under suitable conditions, atoms emit a small number of specific discrete frequencies of E-M radiation.

If an object made of a transparent substance is so shaped that different parts of the incident light must travel different distances in the substance, an incident light beam will exit from the substance with the component frequencies of light in the beam spread out in order of frequency. Such an object is called a prism and a type of prism and its effect are depicted in Figure 15-3(a), below. Water droplets can act as prisms, and when they do the resulting effect is the rainbow. Such an analysis of light (or other radiation) into its component frequencies by the method of a prism or a prismatic effect is called a *spectrum* (plural: *spectra*).



Continuous Spectrum
Figure 15-3(a)

When a gas composed of only one type of atom (one element, Hydrogen, for example) is excited (given energy by heating or other means) the gas will emit radiation. That emitted radiation, when passed through a prism, is disclosed to contain only a small number of sharp specific lines of different colors, not the continuous band of a rainbow. The spectrum so obtained is characteristic of the particular element, that is, the spectrum of a particular element always contains the same specific set of frequencies and only those. See Figure 15-3(b), on the following page. (The terminology "light" and "color" is being used symbolically here. Many of the lines of line spectra are at higher frequencies than those of light.)



Characteristic Line Spectrum
Figure 15-3(b)

Atoms emit only certain specific characteristic frequencies of radiation, and those are only emitted if energy is first supplied. The resulting spectra are called *emission spectra*. With no excitation there is no radiation. It also happens that, if white light is passed through a gas composed of only one element and then through a prism the spectrum that results is the full "rainbow" of white light less a small number of discrete lines, discrete frequencies, that the gas has apparently removed from the beam of light. (Such spectra are called *absorption spectra*.) The frequencies removed are the exact same ones as emitted by that gas when it is excited. Apparently the atoms in the gas absorb the same characteristic frequencies of radiation that they emit when excited.

Measurement and analysis of the line spectra of Hydrogen disclosed that the lines in the spectrum can be grouped into families of lines, which are called series and named after the original researcher: the Lyman series, the Balmer series, etc. It was found that the lines of any series could be fitted to a simple mathematical formula and then all of the series combined into an overall formula. The formula for the line spectra of Hydrogen is given in equation 15-2, below.

(15-2) $$\frac{1}{\lambda} = R \cdot \left[\frac{1}{f^2} - \frac{1}{i^2} \right]$$

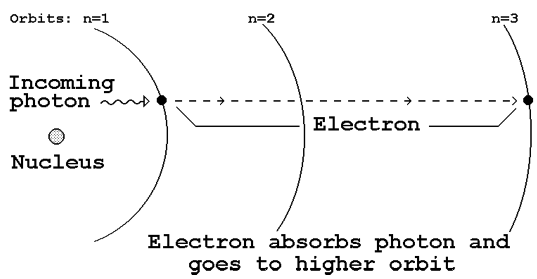
[λ = wavelength of line
f = series nr: 1, 2, ...
i = f+1, f+2, ...
R = a constant called
the Rydberg Constant]

The lines in the Hydrogen spectrum obtained from the formula for *f = 1* with *i = 2, 3, ...* correspond to the first (Lyman) series, for *f = 2* with *i = 3, 4, ...* to the Balmer series, etc.

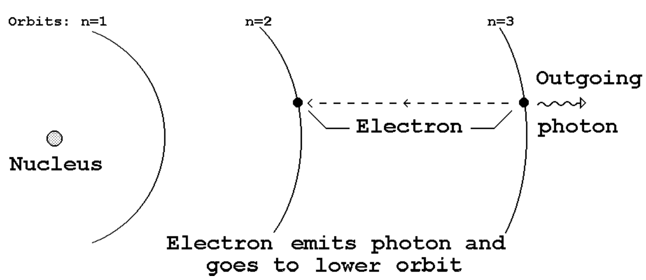
The hypothesis for this behavior, and for the orbital structure of the atom is due to the physicist Bohr. It is that the electrons can exist in a stable state without radiating only in certain discrete orbits, all other orbits being unstable so that electrons in them lose energy and fall out of orbit because of radiating as expected. (No reason is given for the stable orbits being stable, it is simply accepted as apparent fact.)

Each such stable orbit has a certain amount of energy. The orbit closest to the nucleus has the least energy and those farther out have more. (The difference between that energy and the energy of an electron that is completely free of the atom would be the energy that a photon would have to supply in the photoelectric effect for that electron to be released from the atom.) The hypothesis is that the discrete lines in the line spectra of atoms are due to electron transitions between the stable orbits. This would operate as follows.

When light or other energy is supplied to the gaseous element, if an electron in a low orbit receives a photon of just the correct energy so that when added to the electron's current orbit's energy it equals the energy of a specific stable higher orbit then the electron absorbs the photon and goes to the higher stable orbit. (See the transition from the $n = 1$ orbit to the $n = 3$ orbit in Figure 15-4(a), below, for example.) This kind of action produces the absorption line spectrum where the only photons that can interact with an orbital electron are those of energy corresponding to the exact difference between the energy of two stable orbits. Recalling equation 15-1, that the photon energy is $W = h \cdot f$, such discrete photon energies correspond to discrete frequencies, f.



Photon Absorbtion - Absorbtion Spectral Line
Figure 15-4(a)



Photon Emission - Emission Spectral Line
Figure 15-4(b)

If an *excited electron* (one already in a higher orbit that must have gotten there by interaction with a photon as just described) emits a photon of just the correct energy so that the electron's energy changes to that of a lower energy stable orbit then the electron moves to the lower orbit. (See the transition from the $n = 3$ orbit to the $n = 2$ orbit in Figure 15-4(b), above, for example.) The electrons can only emit photons of such correct energies. Such actions account for the emission spectra having only their specific characteristic lines. Since the line spectra are found to exactly correspond to the behavior of equation 15-2 it is then hypothesized that equation 15-2 is a description of, or corresponds to, the stable orbits

For atoms having more than one orbital electron the interaction of the multiple charges makes the problem quite complicated and introduces other effects. For Hydrogen, with only one orbital electron, however, the interaction and its calculations are quite simple and direct. The development is as follows in outline. A precise development will be presented shortly in terms of centers, waves and so forth.

> (1) Bohr's first postulate was that the Coulomb attraction between the orbital electron and the nucleus correctly curves the electron path into the orbit.

(15-3) Centripetal Force = Coulomb Attraction

$$\frac{m \cdot v^2}{r} = \frac{c^2 \cdot q^2}{r^2}$$

[m = mass of the orbital electron
v = the electron orbital velocity
r = the (circular) orbit radius
q = the charge of the electron and of the proton Hydrogen nucleus
c = the speed of light, as usual]

> (2) Bohr's second postulate was that the stable orbits are such that the angular momentum of the orbital electron is an integral multiple of Planck's constant divided by 2π.

(15-4) Angular Momentum = Integer Multiple of $^h/_{2\pi}$

$$m \cdot v \cdot r = \frac{n \cdot h}{2\pi} \qquad [n = 1,\ 2,\ \ldots]$$

> (3) Expressing the orbital transitions as from initial orbit i to final orbit f, calculating the net total energy of the electron in orbit (the sum of its kinetic and potential energies), using the above two postulates to define the orbits, and using equation 15-1 to convert energy changes to photon frequency (and, thus, to wavelength) equation 15-5 is obtained.

(15-5)

$$\frac{1}{\lambda} = \frac{2\pi^2 \cdot m \cdot q^4}{h^3 \cdot c} \cdot \left[\frac{1}{f^2} - \frac{1}{i^2}\right]$$

Equation 15-5 is in the same form as the experimentally obtained equation 15-2. Moreover, the value of the expression in equation 15-5 corresponding to R in equation 15-2 is in quite good agreement with the value of R.

Of course the actual specific stable orbits are not known. It is hypothesized that they must exist and must satisfy the above. The analysis uses the line spectra to define the stable orbits. Nevertheless, the overall result appears to be a workable model for the atomic electrons. (For the first, the innermost, orbit of Hydrogen: $W = 13.6$ *electron volts*, which is about

$2.2 \cdot 10^{-18}$ *joules*, $r = 5.3 \cdot 10^{-11}$ *meters*, and $v = 2.2 \cdot 10^{6}$ *meters per second*.)

However, there is one more element to the photon-quantum structure.

MATTER WAVES

Einstein proposed the particle nature of light, photons, in 1905. Bohr proposed his orbital model of the atom in 1913. In 1924 DeBroglie reasoned that if light, previously considered a wave, was now shown to behave like a particle sometimes, then perhaps matter, previously considered as particles, might at times behave like a wave. Were a particle of matter to behave at times as a wave then it would have to have a wavelength. The analytical reasoning to obtain the matter wave wavelength was as follows.

First considering a photon, its energy is

$$W_{wave} = h \cdot f \qquad \text{[equation 15-1, again]}$$

and the energy equivalent of a mass, m, is

$$W_{mass} = m \cdot c^2 \qquad \text{[per Einstein and detail notes DN 4]}$$

If the photon equivalent mass, m, actually appears as a wave its energy as a wave must be the same as its energy as a mass. Therefore

$$(15\text{-}6) \qquad W_{mass} = W_{wave} \qquad \text{[equating the two]}$$

$$(15\text{-}7) \qquad m \cdot c^2 = h \cdot f \qquad \text{[substituting per above]}$$

$$(15\text{-}8) \qquad m = \frac{h \cdot f}{c^2} \qquad \text{[solving 15-7 for m]}$$

$$= \frac{h}{\lambda \cdot c} \qquad \text{[substituting } c = \lambda \cdot f \text{ for one of the c's in the denominator]}$$

and, finally,

$$(15\text{-}9) \qquad \lambda = \frac{h}{m \cdot c} \qquad \text{[solving 15-8 for } \lambda\text{]}$$

$$= \frac{h}{\text{photon momentum}}$$

recognizing that momentum is defined as the product of mass and its velocity and the velocity of the photon is c. (The photon has mass in kinetic form, the above mass; however, its mass in rest form is zero.)

Photon wavelength equals h divided by the photon momentum. DeBroglie hypothesized that the wave aspect of a particle of matter should have an analogous value; the matter wavelength, λ_{mw}, should be

$$(15\text{-}10) \qquad \lambda_{mw} = \frac{h}{\text{particle momentum}} = \frac{h}{m \cdot v}$$

This hypothesis led to three results.

First - Diffraction patterns were experimentally obtained from electrons. Diffraction being a specific characteristic of waves and electrons being matter the wave aspect of matter was established. In the experiments the expected wavelength, equation 15-10, was verified.

Second - Applying the DeBroglie *matter wavelength* to Bohr's *stable orbits* it was found that each of the stable orbits had a circumferential path length that was equal to the matter wavelength of the orbiting electron or was an integer multiple of the electron's matter wavelength. Without saying "why" the stable orbits are stable, this gave a special aspect to them, a pattern of behavior tending to support the Bohr model of the atom.

Third - The entire field of *quantum mechanics* followed from applying the principle of quantization, the concept that Planck first introduced to obtain a theoretical black body radiation curve that matches experimental reality as in Figure 15-1. Quantum mechanics is the development of the extensions of quantization and the wave aspect of matter to the theoretical description and analysis of all or most atomic behavior.

Thus developed, and now exists, the quandary in which 20th Century physics finds itself. Electromagnetic theory, Maxwell's Equations, and all that they led to, which were so successful at supplying a comprehensive description of radiation in general and of all its wave phenomena, are unable to correctly explain black body radiation, the photoelectric effect and atomic line spectra. On the other hand, the quantum theory and the photon seem to go far toward explaining those phenomena that the wave aspect cannot, but the quantum point of view is unable to explain the aspects of radiation that require wave treatment.

Perhaps the greatest contradiction in the photon theory is as follows. The wavelength of light is in the range of 10^{-7} meters. Atomic dimensions are on the order of 10^{-10} meters so that if a photon, whether a "wave packet" or not, is to contain wavelength data relevant to the light that it represents, it must then have dimensions that are on the order of $10^3 = 1000$ times the size of an entire atom. Clearly this is completely at variance with the photon explanation of the photoelectric effect and of line spectra of atoms.

Referring to Figure 15-4, for example, we would have, relatively speaking, basketball size photons interacting with grain of sand size atoms, the basketball-photon managing to focus its action on one germ-size electron in the sand grain size atom without disturbing any of the rest of the atom. (It can be shown, using the principles of information theory in communications analysis, that representation of a frequency requires at least one sample per half wavelength. A photon would have to be at least a half wavelength in "size").

To present the analysis of these phenomena in terms of the Universal Physics, which resolves the dilemma and incorporates the entire body of phenomena into the simple unified reality already developed in the preceding sections, the development will now proceed through the four major subject areas just presented, but in reverse order, namely: matter waves, electron orbits, and photons.

Matter Waves in Universal Physics

Of course, the motion in space of an individual center-of-oscillation should involve or generate a wave pattern in space. It was from other considerations that DeBroglie hypothesized and, subsequently, Davisson and Germer experimentally detected matter waves. DeBroglie's hypothesized wavelength of the matter waves was confirmed (equation 15-10, that the matter wavelength is inversely proportional to the matter's momentum, Planck's constant being the constant of the proportionality).

Unfortunately, the same line of reasoning as used to obtain the matter wavelength cannot obtain a correct matter wave frequency. If one reasons, analogously to the derivation of λ_{mw}, that the kinetic energy of the particle of matter should correspond to its matter wave frequency, f_{mw}, as

(15-11)

$$f_{mw} = \frac{W_k}{h} \quad \text{[}W_k \equiv \text{kinetic energy and dividing by h uses equation 15-1 to get the frequency]}$$

$$= \frac{\frac{1}{2}\cdot m\cdot v^2}{h}$$

then the velocity of the matter wave is

(15-12)

$$v_{mw} = \lambda_{mw}\cdot f_{mw}$$

$$= \left[\frac{h}{m\cdot v}\right]\cdot\left[\frac{\frac{1}{2}\cdot m\cdot v^2}{h}\right] = \frac{1}{2}\cdot v$$

a result that states that the matter wave moves at one half the speed of the particle. That is obviously absurd as they must move together each being merely an alternative aspect of the same real entity. For them not to move together would be as absurd as for the particle aspect of light to move at a different speed than its wave aspect, the photon not arriving coincident with the E-M wave.

It is no help in resolving this difficulty if relativistic mass is used (as it should be in any case) since the same mass appears in both numerator and denominator of equation 15-12 where they simply cancel out. It is also no help to hypothesize that it is the total energy, not just the kinetic energy, that yields the matter wave. Such an attempt attributes a matter wave to a particle at rest. It also gives the resulting matter wave velocity as c^2/v, which has the matter wave racing ahead of its particle. No, the two must keep pace with each other since they are the same thing merely looked at in one or the other of two alternative ways.

The solution to this problem results from the nature of centers-of-oscillation and their behavior when in motion. In section *13 - A Model for the Universe (3) - Motion and Relativity* the motion of centers was analyzed. It was pointed out that kinetic energy does not really correspond to anything at the center-of-oscillation, particle, level. It is merely the net energy increase due to motion. A new concept / quantity, energy-in-kinetic-form was introduced and it was shown that the mass- / energy-in-kinetic-form corresponded directly to the behavior of the center in motion.

Using mass- and energy-in-kinetic-form to obtain the frequency of the matter wave proceeds as follows.

(15-13)
$$f_{mw} = \frac{m_k \cdot c^2}{h}$$
[equation 15-11, but using mass-in-kinetic-form times c^2 which is energy-in-kinetic-form]

$$= \left[m_v \cdot \frac{v^2}{c^2}\right] \cdot \frac{c^2}{h}$$
[substituting for m_k per equation 13-21, where m_v is the relativistic mass]

$$= \frac{m_v \cdot v^2}{h}$$

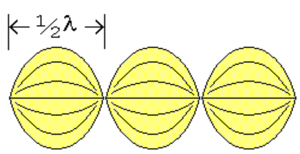
Using this result for matter wave frequency and using relativistic mass in equation 15-10 for the matter wavelength the velocity of the matter wave then is

(15-14)
$$v_{mw} = f_{mw} \cdot \lambda_{mw}$$
$$= \left[\frac{m_v \cdot v^2}{h}\right] \cdot \left[\frac{h}{m_v \cdot v}\right]$$
$$= v$$

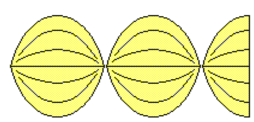
and the wave is traveling with, as the particle.

The matter wave, traveling at the same velocity as the particle of matter, is like a kind of *standing wave* relative to the particle. A standing wave is a wave oscillating in place but without moving in any direction. A common, every-day experience of standing waves is the oscillation of the string of a musical instrument or the waves that appear in a rope held motionless at one end and moved back and forth at the other end (at a suitable rate according to the dimensions of the rope).

Such a standing wave depends on the length of the oscillating string, rope or whatever containing an integral number of quarter wavelengths of the oscillation at the frequency involved. See Figure 15-5, below.



(a)
With both ends fixed in position the standing wave must have an even integral number of ¼ wavelengths in the length (e.g. a musical string instrument).



(b)
With an end free to move the standing wave must have an odd integral number of ¼ wavelengths in the length. (As the above rope example, the right end is free.)

Figure 15-5

A standing wave can be thought of and treated as the sum resultant of two waves traveling in opposite directions through each other. When the two waves are of the same frequency and wavelength then the effect is as in Figure

15-5, above. But if the frequencies and wavelengths are different then a different type of standing wave results. The analysis of this is as follows.

The two waves are

$$\text{(15-15)} \qquad \text{Wave \#1} = A \cdot \mathrm{Sin}(2\pi f_1 t)$$

$$\text{Wave \#2} = A \cdot \mathrm{Sin}(2\pi f_2 t)$$

and the sum is

$$\text{(15-16)} \qquad \text{Wave sum} = A \cdot \left[\mathrm{Sin}(2\pi f_1 t) + \mathrm{Sin}(2\pi f_2 t)\right]$$

which, by using a trigonometric equivalence, can be arranged as

$$\text{(15-17)} \qquad \text{Wave sum} = 2A \cdot \mathrm{Sin}\left[2\pi\left[\frac{f_1 + f_2}{2}\right]t\right] \cdot \mathrm{Cos}\left[2\pi\left[\frac{f_1 - f_2}{2}\right]t\right]$$

The cosine term is at a lesser frequency than the sine term. If the expression for the wave sum is viewed as the (higher frequency) sine portion with the rest of the expression being the amplitude, as in equation 15-18,

$$\text{(15-18)} \qquad \text{Wave sum} = \left[2A \cdot \mathrm{Cos}\left[2\pi\left[\frac{f_1 - f_2}{2}\right]t\right]\right] \cdot \mathrm{Sin}\left[2\pi\left[\frac{f_1 + f_2}{2}\right]t\right]$$

$$= \left[\text{ Varying Amplitude }\right] \cdot \mathrm{Sin}\left[2\pi\left[\frac{f_1 + f_2}{2}\right]t\right]$$

it can be seen that the wave form appears as in Figure 15-6, below.

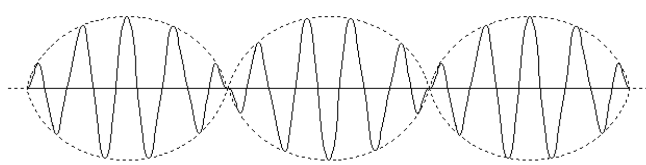


Figure 15-6

The solid-line curve in Figure 15-6 is the overall wave form. The dotted line, called the *envelope*, is the varying amplitude. The overall wave form exhibits a periodic variation according to the envelope. This is called the *beat*. The beat is real, not merely an appearance. For example two sound tones heard simultaneously produce an audible beat that one can hear. It is by listening to the beat that one tunes a piano or other musical instrument.

Matter waves are the beat that results from the center-of-oscillation's forward and rearward oscillations interacting with each other. This develops as follows. For a center in motion at velocity v, as presented in section *13 - A Model for the Universe (3) - Motion and Relativity*,

$$\text{(15-19)} \qquad \lambda_{fwd} = \lambda_v \cdot (1 - {}^{v}/c) \qquad\qquad f_{fwd} = {}^{c}/\lambda_{fwd}$$

$$\lambda_{rwd} = \lambda_v \cdot (1 + {}^{v}/c) \qquad\qquad f_{rwd} = {}^{c}/\lambda_{rwd}$$

The beat frequency, using the "Varying Amplitude" portion of equation 15-18, above, substituting f_{fwd} for f_1 and f_{rwd} for f_2, and then using equation 15-19, is

(15-20)
$$f_{beat} = \frac{1}{2}\cdot\left[f_{fwd} - f_{rwd}\right]$$
$$= \frac{1}{2}\cdot\left[\frac{c}{\lambda_v\cdot(1 - {}^v/c)} - \frac{c}{\lambda_v\cdot(1 + {}^v/c)}\right]$$
$$= \frac{c}{2\cdot\lambda_v}\cdot\left[\frac{[1 + {}^v/c] - [1 - {}^v/c]}{1 - [{}^v/c]^2}\right]$$
$$= \frac{v}{\lambda_v}\cdot\left[\frac{1}{1 - [{}^v/c]^2}\right]$$

(15-21)
$$\lambda_{beat} = \frac{c}{f_{beat}}$$
$$= \lambda_v\cdot\frac{c}{v}\cdot\left[1 - \frac{v^2}{c^2}\right]$$

Substituting in the above for λ_v with

(13-6)
$$\lambda_v = \lambda_r\cdot\frac{1}{\left[1 - \frac{v^2}{c^2}\right]^{1/2}}$$

and for λ_r from

(12-14)
$$m_r = \frac{{}^h/c}{\lambda_r}$$

and for m_r from

(13-13)
$$m_v = m_r\cdot\frac{1}{\left[1 - \frac{v^2}{c^2}\right]^{1/2}}$$

gives the matter wavelength as previously obtained per equation 15-10 (in which the mass must be relativistic mass, m_v, of course).

(15-10)
$$\lambda_{mw} = \frac{h}{m_v\cdot v}$$

The "wave aspect of matter" is, then, simply the natural mode of behavior of a center-of-oscillation in motion. The matter wave effect is merely one of the many consequences of the effects that occur in a center's oscillation when it is in motion as analyzed in section *13 - A Model for the Universe (3) - Motion and Relativity*.

In section *12 - A Model for the Universe (2) - Mass and Matter* it was presented that Planck's constant had not been demonstrated (at that point) to apply to the oscillation of a center, that it was only validated for photons. The above use of the constant in the treatment of matter waves now demonstrates the general validity of using Planck's constant with center and wave oscillations.

A moving center-of-oscillation as "seen" by an external observer appears to the observer as the waves propagated by the center in his direction appear. But, if one could, somehow, actually "see" the center itself pulsating as it does, the case would be different. The interaction of the forward and rearward oscillations, which produce a beat at the matter wave frequency, are real. The effect is as follows (repeating equations 15-15 through 15-18, which were for any general oscillation, but now using the oscillations of a center-of-oscillation in motion).

(15-15A)
$$\text{Wave \#1} = A\cdot[1 + \text{Sin}(2\pi f_1 t)] \qquad \text{[forward wave]}$$
$$\text{Wave \#2} = A\cdot[1 + \text{Sin}(2\pi f_2 t)] \qquad \text{[rearward wave]}$$

[Note: $1 - \cos(x) \equiv 1 + \cos(180° - x)$
$\equiv 1 + \sin[90° - (180° - x)]$
$\equiv 1 + \sin(x - 90°)$
and the 90° phase is irrelevant, of course.]

The sum is

(15-16A)
$$\text{Sum} = A\cdot\left[2 + \text{Sin}(2\pi f_1 t) + \text{Sin}(2\pi f_2 t)\right]$$

which, again using a trigonometric equivalence, can be arranged as

(15-17A)
$$\text{Sum} = 2A + 2A\cdot\text{Sin}\left[2\pi\left[\frac{f_1 + f_2}{2}\right]t\right]\cdot\text{Cos}\left[2\pi\left[\frac{f_1 - f_2}{2}\right]t\right]$$

Again, the cosine term is at a lesser frequency than the sine term. If the expression for the wave sum is viewed as the (higher frequency) sine portion with the rest of the expression being the amplitude, as in equation 15-18A,

(15-18A)
$$\text{Sum} = 2A\cdot\left[1 + \text{Cos}\left[2\pi\left[\frac{f_1 - f_2}{2}\right]t\right]\right]\cdot\text{Sin}\left[2\pi\left[\frac{f_1 + f_2}{2}\right]t\right]$$

$$= 2A\cdot\left[\begin{array}{c}\text{[1 + Cosine]}\\ \text{Form of Varying}\\ \text{Amplitude}\end{array}\right]\cdot\text{Sin}\left[2\pi\left[\frac{f_1 + f_2}{2}\right]t\right]$$

In the case of a center-of-oscillation $f_1 = f_{fwd}$ and $f_2 = f_{rwd}$. Likewise, A is U_c, the center-of-oscillation average amplitude, the oscillation being $U_c\cdot[1 - Cos(2\pi\cdot f\cdot t)]$ per equation 12-21. The wave form appears as in Figure 15-7, below, for the forward-rearward interaction and the matter wave beat of the center's pulsation as it would be "seen" from the side relative to its direction of motion.

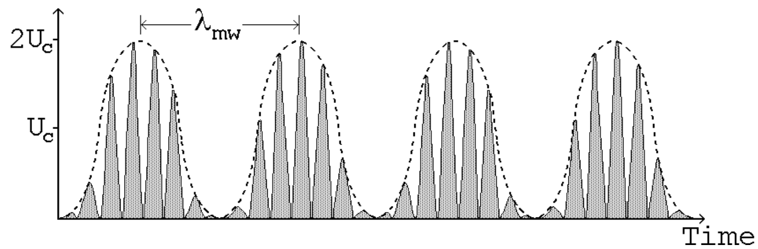


Figure 15-7
The Forward-Rearward Pulsation of a Center in Motion, Which is the Matter Wave

The center's pulsation at right angles to the direction of motion, that is as viewed from "in front" or "behind" would be "seen" as a uniform constant amplitude oscillation at amplitude U_C in all directions. In the direction of motion the center's effective amplitude varies, but the average value remains the same, U_C. The cross-section and responsiveness also vary but have the same average value. (Several implications of this matter wave behavior of the center in motion are treated further on in this section.)

ELECTRON ORBITS IN ATOMS

The electron orbits in atoms are:

> (1) a balance of the orbital path's centripetal force and the Coulomb attraction between the electron and the atomic nucleus (orbits such that the Coulomb attraction is just the correct amount to continuously deflect the electron, at its velocity, into the curved orbital path),
>
> (2) at intervals such that the energy differences between the various orbits correspond to the energy of the light of the various characteristic lines of the emission and absorption spectra, so that electron transitions between orbits correspond to emission or absorption of photons of those energies, and
>
> (3) such that the length of the orbital path of revolution of the electron around the atomic nucleus is exactly an integer number, one or more, of the matter wavelength of that orbiting electron.

It is because of (3), above, that only those orbits, are stable. It is the above conditions that define the orbits.

In order to present this it first is necessary to review the matter of charged particles and E-M radiation. Traditional 20th Century physics contends that acceleration of a charged particle produces E-M radiation. That matter has been treated correctly in the foregoing sections, but not explicitly.

> The explicit fact is that *change of speed* of a charged particle produces E-M radiation. *Change of direction without change of speed has no such effect*.

Of course, change of speed requires acceleration; however not all acceleration produces E-M radiation, only acceleration that changes the speed. Acceleration that changes only the direction of the charged particle accelerated does not result in the particle radiating E-M waves. This is a serious departure from the position of traditional 20th Century physics, validated as follows.

> (1) E-M radiation requires energy to propagate in the E-M wave. That energy must come from the electrical charges that are the source of the radiation. Change in charged particle speed involves energy change. Change in its direction, only, involves no change in its energy.
>
> (2) A coil of electrical wire carrying a constant electric current does not radiate E-M radiation even though the current path is curved (nor has it ever been contended otherwise). But the charged particles flowing as the current in the coil must be continuously accelerated into the curved path of the coil of wire. Their speed remains constant since the current is constant. The acceleration is change of direction only.
>
> While in a coil of wire that is obscured by particle collisions and the resulting electrical resistance, such does not occur in a superconducting ring in which, once it is initiated, a constant current appears to circulate forever, without radiating. Likewise, the radiation from cyclotrons and other particle accelerators occurs because the particles' speeds change.
>
> (3) A static electric field contains a certain amount of potential energy. If the field increases the energy increases and vice versa. A static magnetic field likewise contains a certain amount of potential energy. Likewise, if the field increases the energy increases and vice versa. E-M radiation occurs by those fields first increasing and then decreasing. Because when the fields decrease the greater energy that was in the fields cannot return to the charged particle(s) from which it came, and because that energy is represented in the U-waves which are traveling away from the center at the speed of light, c, the only thing that the excess energy can do is propagate off into the distance with the U-waves in which it exists.

That is E-M radiation. It requires a change of center speed, a change of source charged particle speed, so that the consequent energy changes occur. A change of center direction at constant speed will not produce field increase and decrease, will not produce energy change, and therefore will not produce E-M radiation.

Now, that being the case, the entire problem of the Bohr atom becomes turned on its head and must be restated. The problem is not that the electron orbits should all be unstable and radiate their energy so that they spiral into the nucleus, with the question left as to why that does not happen to the "stable" orbits. Rather, the problem is that <u>all of the orbits should be stable</u>, so why does only the small number that we call the "stable" orbits have stability and all of the rest not ?

Of course an electron that is not in orbit but is spiraling in toward the nucleus does radiate E-M waves. That is the way it loses energy, which it must do to "spiral in". But, an electron in orbit, the Coulomb attraction toward the nucleus providing exactly the required centripetal force, does not radiate. It remains comfortably in its orbit like a planet in the solar system. Or, more precisely, that is what it should do in terms of correct 20th Century physics. In fact, it is able to so remain only if the orbital path length is an integral multiple of the particle's matter wavelength. Why ?

The answer lies in the nature of the Coulomb force. In traditional 20th Century physics the Coulomb force is a smooth continuous attraction or repulsion. In Universal Physics it is the macroscopic effect of the incoming U-waves interacting with the encountered center's own oscillation, the wave interacting with the responsiveness. It is the extremely rapid repetition of successive impulses. (For the innermost Hydrogen orbit the electron frequency is such that there are over 20,000 electron oscillation cycles per orbital path. The proton nucleus goes through approximately 40,000,000 cycles per orbital pass of that electron.)

Figure 15-7, above, which depicts the effect of the matter wave on the pulsation of the center when in motion, is presented for one particular pair of values of the frequencies, f_{fwd} and f_{rwd}. The values were chosen to make it possible to depict the effect in a practical figure. Nevertheless, the figure makes clear that for any pair of values of f_{fwd} and f_{rwd} that might be the case in practice, while the average responsiveness of the center corresponds to the particle mass, a sample of the center's behavior over any span other than one or an integral number of matter wavelengths will not exhibit that average responsiveness. The correct average responsiveness is only obtained over an integral number of matter wavelengths.

Consequently, if the electron's orbit is not an integral number of matter wavelengths long the electron's responsiveness will vary from orbital pass to orbital pass. The Coulomb attraction per orbital pass will not be the correct amount to maintain the orbit. The electron will be either over-attracted by the positive nucleus or under-attracted by it during any particular orbital pass. In either case the orbit will be unstable.

It is not "quantization of the angular momentum of the orbital electron" that determines the stable orbits as proposed by traditional 20th Century physics. Rather it is that the Coulomb attraction between the orbital electron and the nucleus produces the match to the required centripetal force that results in a stable orbit only when the orbital path is an integral number of matter wavelengths long because only then does the orbital electron responsiveness or mass exhibit the correct average value per orbit. There is no "quantization" as the term is used in traditional 20th Century physics.

The statement that the orbital electron's angular momentum is quantized, as in equation 15-4

$$m \cdot v \cdot R = n \cdot \frac{h}{2\pi} \qquad [n = 1,\ 2,\ \ldots] \tag{15-4}$$

is merely a mis-arrangement of

$$2\pi \cdot R = n \cdot \frac{h}{m \cdot v} = n \cdot \lambda_{mw} \tag{15-22}$$

the statement that the orbital path, $2\pi \cdot R$, must be an integral number of matter wavelengths, $n \cdot \lambda_{mw}$, long. The latter statement has a clear, simple, operational reason for its necessity. The statement of traditional 20th Century physics is arbitrary and is justified only because it produces the correct result, even if without having an underlying rational reason.

Turning now to the characteristics of the stable orbits the analysis is as follows. Figure 15-8, below, illustrates the situation for Hydrogen. The single orbital electron of the Hydrogen atom does not orbit around the center of the proton nucleus of the atom. Rather, the particles revolve about their common center of mass at point. The common center of mass is the imaginary or hypothetical point on a line joining the two particles at which point they would "balance" (as on a playground see-saw).

Figure 15-8, below illustrates the two particles revolving about their common center of mass marked *CoM* in the figure.

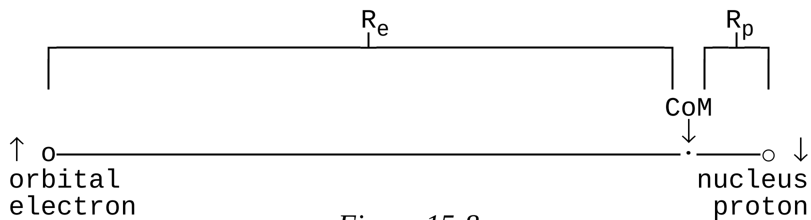


Figure 15-8
Particle Motion in the Hydrogen Atom (Not to scale)

The location of the *CoM* is determined as follows.

(15-23) $R = R_e + R_p$ [Definition of R]

(15-24) $R_e \cdot m_e = R_p \cdot m_p$ [Definition of common center of mass where:

m_e = orbital electron rest mass
m_p = rest mass of nucleus, a proton in this case]

$$R_e = R_p \cdot \frac{m_p}{m_e} = [R - R_e] \cdot \frac{m_p}{m_e}$$

$$= R \cdot \frac{m_p}{m_p + m_e} = R \cdot \frac{m_p/m_e}{m_p/m_e + 1}$$

Let

(15-25)
$$k = \frac{m_p}{m_p + m_e} = \frac{m_p/m_e}{m_p/m_e + 1}$$

so that, from equation 15-24

(15-26) $R_e = k \cdot R$

The centripetal acceleration for circular motion is v^2/r. That times the mass is the *centripetal force*, which the Coulomb attraction must produce.

Then, using Standard International, SI, units

(15-27) Centripetal force [radius is R_e] = Coulomb attraction [radius is $R=R_e+R_p$]

$$\frac{m_e \cdot v_e^2}{R_e} = \frac{q^2}{4\pi \cdot \varepsilon_0 \cdot R^2}$$

$$\frac{m_e \cdot v_e^2}{k \cdot R} = \frac{c^2 \cdot q^2}{10^7 \cdot R^2}$$ [Using equation 15-26 and $1/\varepsilon_0 = 4\pi \cdot 10^{-7} \cdot c^2$]

(15-28) $$\frac{c}{v_e} = \frac{R \cdot m_e \cdot v_e \cdot 10^7}{k \cdot q^2 \cdot c}$$ [Algebraic rearrangement of equation 15-27]

(15-29) $$2\pi \cdot R_e = n \cdot \lambda_{mw}$$ [Each stable orbital path equals an integral number of matter wavelengths. n ≡ integer 1, 2, ...]

$$2\pi \cdot k \cdot R = n \cdot \frac{h}{m_e \cdot v_e}$$ [From equations 15-10 and 15-26]

(15-30) $$n = \frac{2\pi \cdot k \cdot R \cdot m_e \cdot v_e}{h}$$ [Algebraic rearrangement of 15-29]

The ratio of these is

(15-31) $$\frac{\text{equation 15-28}}{\text{equation 15-30}} = \text{equation 15-28} \cdot \frac{1}{\text{equation 15-30}}$$

$$\frac{c/v_e}{n} = \left[\frac{R \cdot m_e \cdot v_e \cdot 10^7}{k \cdot q^2 \cdot c}\right] \cdot \left[\frac{h}{2\pi \cdot k \cdot R \cdot m_e \cdot v_e}\right]$$

$$\frac{c}{v_e} = \frac{n}{k^2} \cdot \frac{h}{2\pi \cdot 10^{-7} \cdot q^2 \cdot c}$$

The physicist will recognize in this formulation the reciprocal, α^{-1}, of the *fine structure constant*, α, of 20th Century physics, where

(15-32) $$\alpha = \frac{\tfrac{1}{2} \cdot \mu_0 \cdot c \cdot q^2}{h}$$ [μ_0 being $4\pi \cdot 10^{-7}$ in SI units]

the factor in Sommerfeld's electron orbital motion derivation to account for the "fine structure" found in the line spectra when a spectroscopic instrument of sufficiently high quality and resolution is used to obtain the spectra. (The fine structure will be dealt in a later section.)

Thus, equation 15-31 becomes

(15-33) $$\frac{c}{v_e} = \frac{n \cdot \alpha^{-1}}{k^2}$$

The most accurate source for the value of the various fundamental constants of the universe is the Committee on Data for Science and Technology (CODATA) of the International Council of Scientific Unions. As new data and better measurements become available these constants are revised to the new more accurate values. The last such revision was that of 1986. Referring to the *Codata Bulletin - The 1986 Adjustment of the Fundamental Physical Constants*, E Richard Cohen and Barry N Taylor, Pergamon Press, November 1986, Table 15-9 below lists the data needed for calculating c/v_e per equation 15-33 as well as some other constants that will be used shortly.

Datum	The one standard deviation uncertainty in the last two digits	
$\alpha^{-1} = 137.0359895$	(61)	0.045 ppm
$\frac{m_p}{m_e} = 1836.152701$	(37)	0.020 ppm

Table 15-9

Using the above value of m_p/m_e the values of k and c/v_e are

(15-34) $k = 0.9994556794$ [From equation 15-25]

(15-35) $$\frac{c}{v_e} = \frac{n \cdot \alpha^{-1}}{k^2}$$ [From equation 15-33]

$$= n \cdot 137.1852944$$

where:

k = the adjustment for the CoM, the center of orbital revolution, being the common center of mass rather than the location of the nucleus

n = 1, 2, ... and is the orbit number, which is also the number of matter wavelengths in the orbital path

v_e = the electron velocity.

The frequency of the photon emitted when the orbital electron falls from outer, initial orbit i to inner, final orbit f equals the energy that the electron loses divided by Planck's constant per equation 15-1.

(15-36) $$f_{ph} = \frac{1}{h} \cdot \left[\begin{matrix} \text{Electron Total} \\ \text{Energy in} \\ \text{Initial Orbit} \end{matrix} - \begin{matrix} \text{Electron Total} \\ \text{Energy in} \\ \text{Final Orbit} \end{matrix} \right]$$

$$= \frac{1}{h} \cdot \left[W_i - W_f \right]$$

The total energy in any such orbit is

(15-37) $$W_{orbit} = W_{rest} + W_{kinetic} + W_{potential}$$

where, in this case, the rest energy can be neglected because it cancels in the subtraction of equation 15-36. (This calculation is being done in the terms of traditional 20th Century physics, as was the original Bohr development of course, that is using kinetic energy not energy in kinetic form.)

The potential energy in any orbit is the Coulomb attraction times the distance through which it acts. The electron cannot shift without the nucleus likewise shifting, however. (In general everything said of the orbital electron applies also to the nucleus, which likewise is orbiting the common center of mass, except that the amounts are different. The effect of nuclear motion is treated in detail notes *DN 8 - Analysis of Some Minor Effects on Orbital Electron Motion* after the end of this section.) The potential energy between the electron and the nucleus operates with share k to the electron and share $[1-k]$ to the nucleus, where k is per equation 15-25, above. The overall potential energy and that allocation of it are derived in detail notes *DN 9 - Orbital Electron Energy Analysis* immediately after detail notes *DN 8*.

Consequently

(15-38) $$W_{potential} = k\cdot\left[-\frac{q^2}{4\pi\cdot\varepsilon_0\cdot R^2}\cdot R_e\right] \quad \text{[from equation 15-7]}$$

$$= k\cdot\left[-\frac{m_e\cdot v_e^2}{k\cdot R_e}\cdot R_e\right] \quad \text{[" " "]}$$

$$= -\,m_e\cdot v_e^2$$

The kinetic energy is, of course

(15-39) $$W_{kinetic} = \frac{1}{2}\cdot m_e\cdot v_e^2$$

so that equation 15-37 becomes

(15-40) $$W_{orbit} = \frac{1}{2}\cdot m_e\cdot v_e^2 - m_e\cdot v_e^2 = -\frac{m_e\cdot v_e^2}{2}$$

and f_{ph}, equation 15-36, becomes

(15-41) $$f_{ph} = \frac{1}{h}\cdot\left[\left[-\frac{m_e\cdot v_e^2}{2}\right]_i - \left[-\frac{m_e\cdot v_e^2}{2}\right]_f\right]$$

$$= \frac{m_e}{2h}\cdot\left[[v_e^2]_f - [v_e^2]_i\right]$$

Solving equation 15-33 for v_e

(15-42)
$$v_e = \frac{k^2 \cdot c}{\alpha^{-1}} \cdot \frac{1}{n}$$

which, when substituted into equation 15-41, results in

(15-43)
$$f_{ph} = \frac{m_e}{2h} \cdot \left[\frac{k^2 \cdot c}{\alpha^{-1}}\right]^2 \cdot \left[\frac{1}{n^2_f} - \frac{1}{n^2_i}\right]$$

and, dividing by c

(15-44)
$$\frac{1}{\lambda_{ph}} = \frac{f_{ph}}{c} = \frac{m_e \cdot c}{2h} \cdot \left[\frac{k^2}{\alpha^{-1}}\right]^2 \cdot \left[\frac{1}{n^2_f} - \frac{1}{n^2_i}\right]$$

Derived equation 15-44 is of the same form as equation 15-2, which was deduced from experimental data, the actual line spectra of Hydrogen. The two equations are identical if

(15-45)
$$R_\infty = \frac{m_e \cdot c}{2h} \cdot \left[\frac{k^2}{\alpha^{-1}}\right]^2$$

The Codata Bulletin referred to above gives the following values for the constants needed to calculate equation 15-45 other than the value of α^{-1} and data for evaluating k, which were already given in Table 15-9.

Datum	The one standard deviation uncertainty in the last two digits	
$c = 299{,}792{,}458\ ^m/_{sec}$	exact by definition (the meter is now defined in terms of c)	
$h = 6.6260755 \cdot 10^{-34}$ J-sec	(40)	0.60 ppm
$m_e = 9.1093897 \cdot 10^{-31}$ kg	(54)	0.59 ppm
$R_\infty = 10{,}973{,}731.534\ m^{-1}$	(13)	0.0012 ppm

Table 15-10

The Rydberg constant Codata value given in the above table is for $k=1$, and the constant, R_∞, is so defined. With $k=1$ equation 15-45 becomes the defined value

(15-45a)
$$R_\infty = \frac{m_e \cdot c}{2h} \alpha^2$$

Thus the value of R_∞ predicted by the Bohr theory and the actual experimentally measured value of R_∞ agree. (Several fine points with regard to the Bohr Hydrogen atom model are treated in detail notes *DN 8 - Analysis of*

Some Minor Effects on Electron Motion at the end of this section. Those analyses produce no change in the above results.)

Calculating the potential and kinetic energy changes separately as below rather than combined as in equation 15-40, above, (Δ means "change in")

$$(15\text{-}46)\qquad \Delta_{PE} = -\Big[[m_e\cdot v_e^2]_i - [m_e\cdot v_e^2]_f\Big] \qquad \text{[per equation 15-38, above]}$$

$$= -m_e\cdot[v_{e,i}^2 - v_{e,f}^2]$$

$$\Delta_{KE} = ½\cdot[m_e\cdot v_e^2]_i - ½\cdot[m_e\cdot v_e^2]_f$$

$$= ½\cdot m_e\cdot[v_{e,i}^2 - v_{e,f}^2]$$

shows that:

> For an electron transition from an outer orbit to an inner one (with emission of a photon) half of the electron potential energy lost goes to electron kinetic energy increase and half goes to the emitted photon.
>
> For an electron transition from an inner orbit to an outer one (with absorbtion of a photon) half of the electron potential energy gain comes from the kinetic energy loss of the electron and the other half comes from the photon absorbed.

The general analytic procedure employed over the past number of pages for the Hydrogen atom cannot be applied in general to multi-electron atoms. It is not that the basic concept does not apply to multi-electron atoms. The basis of Bohr's hypothesis applies to all atoms, but multiple orbital electrons introduce other effects in addition. Furthermore, the analysis of multiple charged particle interactions rather than the Hydrogen atom's simple two-particle case is cumbersome and impractical. The structure of multiple electron atoms will be addressed shortly. First, however, the detailed nature of the photon and its behavior must be developed.

THE PHOTON

What is the photon ? The analysis so far has verified the atomic structure hypothesis of planetary orbital electrons, a set of discrete stable orbits, and the emission of E-M radiation in conjunction with electron orbit changes in a process where an electron that is disturbed out of its higher orbit falls to one of the stable orbits below emitting the appropriate frequency of E-M radiation to account for the energy change. But the verification of that structure and process raises more questions.

- What disturbs the electron out of its stable orbit ? How ? Why does it seem not to do so for the lowest stable orbit ?
- How does the electron "know" at the beginning of orbital transition to which lower stable orbit it is going. How does it emit exactly the correct radiation and follow the exact correct motion from the beginning of its transition ?
- What determines which of multiple available lower orbits it goes to ?

- What do the electron path and the radiation emitted "look" like ? Why are they so ?

- What is the photon and how does it operate ?

The remainder of the discussion in this section is analysis and treatment of the behavior of the orbital electrons and the related photons. Consequently, the subscript "$_e$" to denote reference to the electron will be omitted, reference to the electron being assumed. The subscript role then becomes available to differentiate between different conditions such as initial and final or rest and at velocity.

The Bohr model analysis presented above is non-relativistic; that is, the effect of the electron's velocity on its mass is neglected. Solving equation 15-35 for the electron velocity, v (v_e in equation 15-35) relative to c the following is obtained.

$$(15\text{-}47) \qquad \frac{v}{c} = \frac{k^2}{n\cdot\alpha^{-1}} = \frac{.9989\ \cdots}{n\cdot 137.1852944}$$

The greatest orbital electron velocity, that for $n = 1$, is less than $^c/_{137}$ so that $[^v/c]^2$ is less than 0.000054. Consequently the relativistic effect is quite small although nevertheless real.

To take relativistic mass increase into account the m_e quantities in equation 15-41, which there were electron rest mass, must be replaced with m_v, electron relativistic mass. (The minus signs within the innermost brackets of equation 15-41 should also be dropped out here. Their purpose was to show that the orbital electron total energy is negative relative to outside of the atom. That is, energy must be added to an orbital electron to raise it to a higher orbit or to free it totally from the atom, the _th orbit.) Equation 15-41, slightly re-arranged then becomes

$$(15\text{-}48) \qquad f_{ph} = \frac{1}{2}\cdot\left[\left[\frac{m_v\cdot v^2}{h}\right]_f - \left[\frac{m_v\cdot v^2}{h}\right]_i\right]$$

$$= \tfrac{1}{2}\cdot\left[f_{mw,f} - f_{mw,i}\right]$$

where: f_{mw} = matter wave frequency per equation 15-13

The electron orbital transition that produces the emission of a photon is a transition from an initial outer orbit to a final inner orbit and must fit, must match to, the following requirements.

- The transition consists of a change from the initial orbit / state to the final orbit / state as in part of a cycle of an oscillation, not a changing to a different state and then returning back as in a full cycle of an oscillation.

- For the same reasons as cited in section *10 - The Probable Beginning*, the transition must be a smooth variation, without any sudden "jump" change. The changes must be smooth in the same sense as was necessary for the beginning of the U-oscillation at the start of the universe and for the same reason: there can be no infinite rate of change.

- The photon radiation is Maxwellian electromagnetic wave and is at one simple frequency, the photon frequency. It therefore must be in the form of a simple sinusoid.

- The theory of information in communications shows that at least a sample every half-cycle of an oscillation is required to specify it sufficiently. Therefore, at least a half cycle of the photon oscillation is required to specify it.

Therefore, for all of the above reasons, the photon must be in the form of a half-cycle of a sinusoidal function of time.

- In the earlier section *14 - A Model for the Universe (4) - Magnetic and Electromagnetic Field* it was shown that the magnetic field is directly proportional to the velocity of the moving electric charge producing that field. Therefore the magnetic field of the photon is directly proportional to the transitioning electron's velocity. Since the photon magnetic field must be a half-cycle sinusoid the transitioning electron's velocity variation must be a half-cycle sinusoid.

- The electron velocity must vary in accordance with the above from the stable velocity of the initial orbit through a period of increase and ending in the stable velocity of the final orbit. (The potential energy lost in the move to a lower orbit appears half in the photon and half in the increase in electron kinetic energy due to its greater velocity per equation 15-46, above).

The combination of these factors results in the specification that the photon must be a half cycle of a pure sinusoidal type variation behaving as presented in Table 15-11, below, and Figure 15-12 on the facing page.

The States and Changes of the Electron Orbital Transition

	Before	During	After
Electron Velocity	$v_{initial\ orbit}$	A smooth transition	$v_{final\ orbit}$
Matter Wave Frequency	$f_{initial\ orbit}$ $=\left[\frac{m_v \cdot v^2}{h}\right]_i$	A smooth transition of $\frac{m_v \cdot v^2}{h}$	$f_{final\ orbit}$ $=\left[\frac{m_v \cdot v^2}{h}\right]_f$
Matter Wavelength	$\lambda_{initial\ orbit}$	A smooth transition	$\lambda_{final\ orbit}$
Photon Activity	--	E-M radiation at frequency $f_{ph}=½\cdot\left[f_{mw,f}-f_{mw,i}\right]$	--

Table 15-11
Electron Orbital Transition Conditions

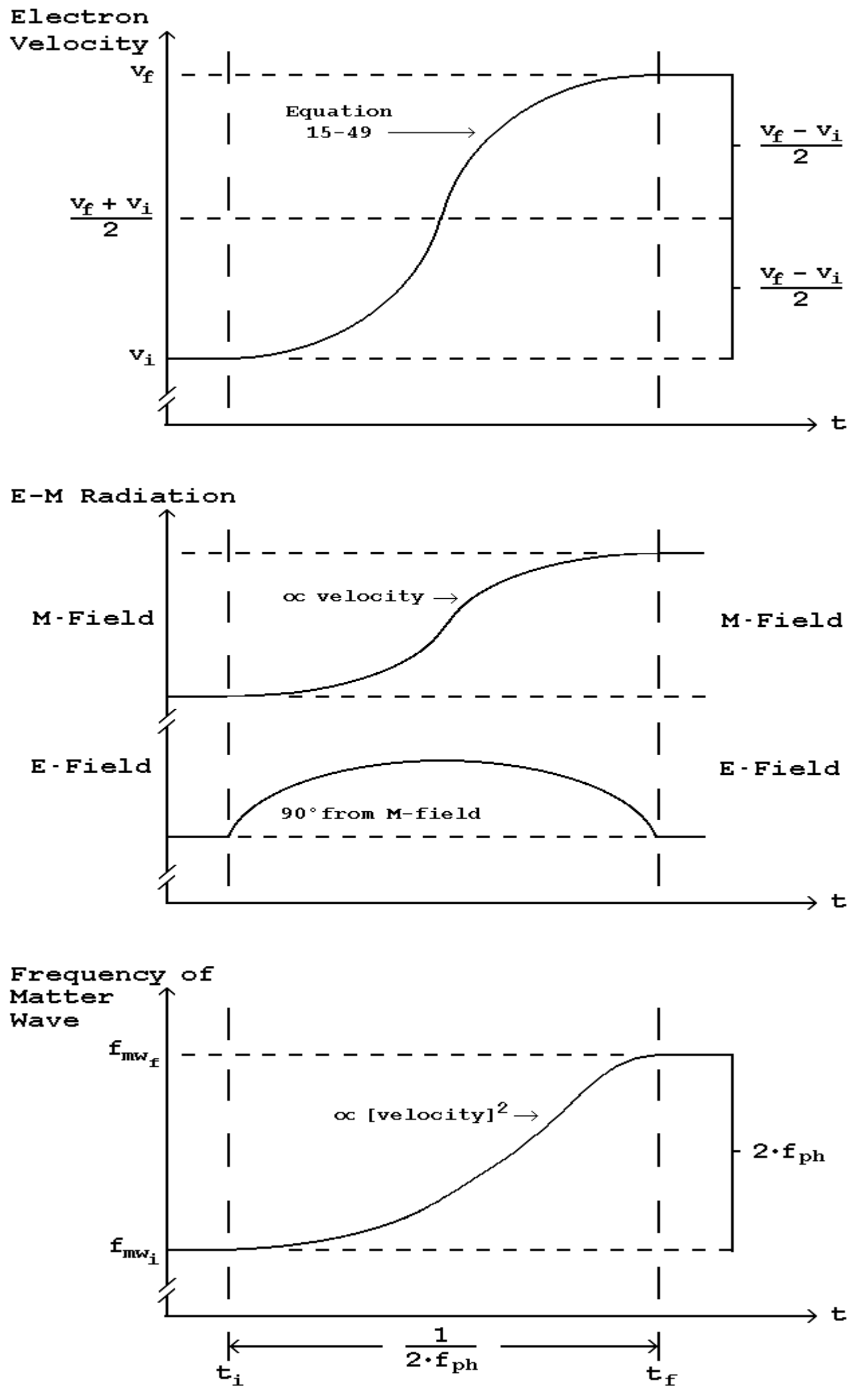


Figure 15-12
The Photon

Equation 15-49, below, is the resulting description of the photon-producing electron orbital transition.

(15-49) (a) Before Electron Orbital Transition

$$v = v_i$$

(b) During the Transition

$$v = \begin{bmatrix}\text{Average of}\\ \text{Initial and}\\ \text{Final Vel's}\end{bmatrix} - \begin{bmatrix}\text{Transition}\\ \text{½ Velocity}\\ \text{Change}\end{bmatrix}\cdot \text{Cos}\left[2\pi\cdot f_{ph}\cdot t\right]$$

$$= \left[\frac{v_f + v_i}{2}\right] - \left[\frac{v_f - v_i}{2}\right]\cdot \text{Cos}\left[2\pi\cdot f_{ph}\cdot t\right]$$

(c) After Electron Orbital Transition

$$v = v_f$$

Where: f_{ph} = photon frequency

$t_f - t_i$ = transition time

$$= \frac{1}{2\cdot f_{ph}} = \text{photon half-cycle}$$

The photon is the U-wave field change associated with the electron's orbital transition from an outer to an inner stable orbit, its velocity shifting upward as a smooth half-cycle sinusoid during a time equal to half the period of the photon cycle. The matter wave shifts upward in frequency in proportion to the electron velocity squared (slightly modified by relativistic m_v) in a smooth transition from the outer to the inner orbit matter wave. The photon frequency is one-half the difference of the initial and final matter wave frequencies.

(The behavior of any electromagnetic radiation is such that the E-M radiation E-field is 90° out of phase with the M-field. The E-field is so shown above. One's initial reaction to its form might be that it violates the requirement for smoothness, that it involves an infinite rate of change. That is not the case because the E-Field curve is not the depiction of any motion, or velocity. It is the change in the spatial distribution of charge because of the transition, not the motion of anything.)

While not necessarily of much analytic significance, knowing the time duration of the electron's orbital transition relative to the electron orbital period is helpful in visualizing the process. That relationship develops as follows.

From equation 15-42

$$v \propto {}^1/_n$$

so that

$$f_{mw} = \frac{m\cdot v^2}{h} \propto {}^1/_{n^2}$$

Neglecting relativistic effects, since

$$f_{ph} = ½\cdot(f_{mw,f} - f_{mw,i})$$

then

$$f_{ph} = ½\cdot f_{mw,f}\left[1 - \frac{n_f^{\,2}}{n_i^{\,2}}\right]$$

The orbital transition takes place in the time of one-half cycle of the photon's frequency. Letting

$$D_{xx} \equiv \text{duration of } xx$$

then

$$D_{ph} = \frac{1}{2 \cdot f_{ph}} = D_{\underline{tr}ansition}$$

$$D_{tr} = \frac{1}{f_{mw,f}\left[1 - \dfrac{n_f{}^2}{n_i{}^2}\right]}$$

$$= D_{mw} \cdot \frac{n_i{}^2}{n_i{}^2 - n_f{}^2}$$

$$= \frac{D_{\text{final orbit}}}{n_f} \cdot \frac{n_i{}^2}{n_i{}^2 - n_f{}^2}$$

In terms of the final orbital period the transition takes place in $1^1/_3$ orbital periods at most $[n_i = 2,\ n_f = 1]$, and in approximately $^1/_2$ or less such orbital periods for most cases $[n_f > 1]$. Since the initial orbital period is approximately $^{n_i}/_{n_f}$ times longer than the final one it can be concluded that the orbital transition and photon emission take place with the electron traveling substantially less than one pass around the nucleus.

There are a number of similarities between an electron falling out of its orbit and the decay of an Earth satellite's orbit so that the satellite falls back to Earth. The first similarity is the situation prior to the fall or decay, when the electron / satellite is continuously in its orbit. Figure 15-13a, below depicts that situation.

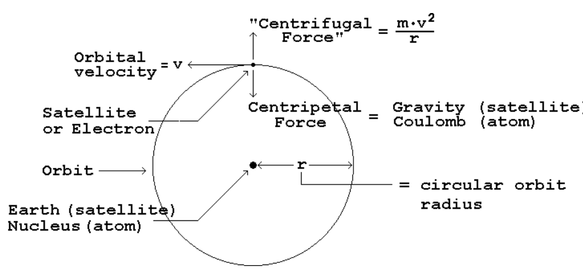


Figure 15-13a
Stable Orbit Mechanics

In accordance with Newton's first law of motion, the orbiting body moves at constant velocity in a straight line unless acted upon by a force. That is, a force is necessary to curve the natural straight line motion into the circular orbit. That force must be in the amount

$$(15\text{-}50) \qquad F_{centripetal} = \frac{m \cdot v^2}{r} = \left[\text{mass}\right] \cdot \left[\begin{matrix}\text{acceleration} \\ \text{required} \\ \text{for a circle}\end{matrix} = \frac{v^2}{r}\right]$$

and is provided by the gravitational attraction of the Earth for the satellite or the Coulomb attraction of the positive atomic nucleus for the negative orbital electron. When the body is in orbit the orbital velocity, v, is such that the $F_{centripetal}$ resulting, per equation 15-50, is exactly provided by the gravitational or Coulomb, as the case may be, attraction that is acting.

Footnote 15-1

The centripetal acceleration of equation 15-50, above, comes about as follows. Referring to Figure FN15-1, below

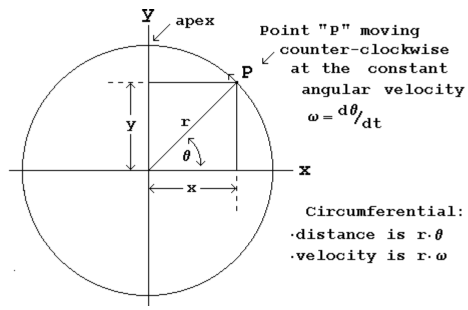


Figure FN15-1

(FN15-1) $y = r \cdot \mathrm{Sin}[\theta] = r \cdot \mathrm{Sin}[\omega \cdot t]$

(FN15-2) $v_y = \dfrac{dy}{dt} = r \cdot \omega \cdot \mathrm{Cos}[\omega \cdot t]$ [Differential calculus per detail notes DN 1]

(FN15-3) $a_y = \dfrac{dv_y}{dt} = -r \cdot \omega^2 \cdot \mathrm{Sin}[\omega \cdot t] = -\omega^2 \cdot y$

When point P is at the apex in the above figure, then $y = r$ so that there, on the circumference of the circle,

(FN15-4) $a_y = -\omega^2 \cdot r = \dfrac{\omega^2 \cdot r^2}{r} = \dfrac{v^2}{r}$

and (negative meaning down in the figure) is directed at the center of the circle, that is, it is the radial inward acceleration. Thus, the radial inward acceleration of the point P moving at constant speed in the circle is v^2/r when the point is at the apex of the circle. However the circle is perfectly symmetrical and the central radial acceleration is the same, v^2/r, at all points on the circle.

That radial acceleration produces no radial motion. It is the rectangular coordinates, x and y, in which a velocity resulting from the acceleration can be seen. From the apex of the circle in the above figure the y coordinate of the point P moves downward at increasing velocity, crosses the horizontal line at its peak speed and then continues downward decelerating until it reaches the nadir of the figure and is back at zero velocity in the y direction. No net energy is expended in that action because the energies involved in the acceleration and the deceleration are equal and opposite. Of course, the radial acceleration, v^2/r, involves no energy because no motion through a radial distance takes place.
