The Mechanism of Orbital Transition

Abstract

We explore the path an electron might take during the absorption and production of photons in transitioning from one orbital to another. Orbital mechanics are used to consider possible transition paths. We conclude that the path is most likely a spiral.

Introduction

In the early 20th century, Nils Bohr proposed that electrons could only orbit the nucleus of an atom at distinct distances, or orbits. This accurately explained the spectral lines caused by photons of light energy emitted by atoms when electrons dropped from an orbit to one closer to the nucleus of the atom. They equally explained the absorption of photons by electrons jumping from an inner orbit to an outer one.

This restriction to distinct orbits contradicted what was known from classical mechanics. For example, a satellite can orbit the earth at just about any distance from the surface, and those distances do not seem to be restricted to a select few.

Since the restriction of electrons to distinct orbits could not be explained by classical mechanics, said restriction contributed to the creation of the theory of quantum mechanics. Initially these orbits were conceived as circular. Later, as physicists attempted to reconcile the dual nature of particles as sometimes acting like waves, the orbits became called orbitals and assumed much more complicated shapes. However, the basic mechanics of spectral lines and distinct orbitals that produce them have not changed.

We proposed earlier that space may be distorted by the creation of a particle, such as a proton [1]. In the early 20th century this possibility was not considered as a potential explanation for the amount of energy electrons absorb or release when transitioning between orbitals. Here we explore the implications of considering the hypothesis that the insertion of a *charged* particle into space is a possible explanation for the unexpected mechanics of electrons orbiting atoms.

Bohr Model

For simplicity we focus on the simple hydrogen atom with one proton in the nucleus and one electron. In the center of the atom is a single proton. The electron that orbits the nucleus does so in distinct orbits. In the original Bohr model, these were circular orbits confined to a succession of spheres. Each sphere is identified by a unique integer number, denoted by n, where n = 1 to ∞. The radius of each sphere was related to the radius of the first one by the exquisite formula

$$r_n = r_1 n^2 \tag{1}$$

where r_n is the radius of the n^{th} orbit.

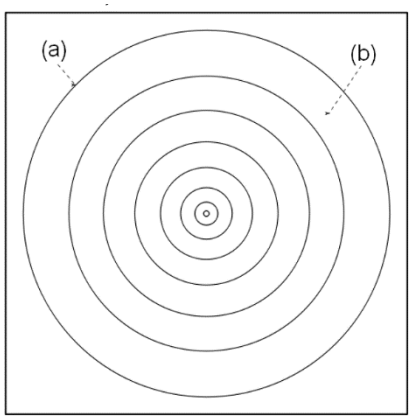

Figure 1. Bohr model of an atom. This figure illustrates only the first 8 electron quantum levels. (a) Quantum level 8; (b) quantum layer 8 (not a Bohr concept.) Drawn to scale: the radius of each quantum level is proportional to the square of its quantum number (Eq. (1).) The nucleus is 10^5 times smaller than electron quantum level 1. The Bohr model was introduced in 1913. Since replaced by more complex models, its simplicity and clarity still make it a useful starting place for any model of atomic phenomena.

The Bohr model remains an excellent match to the known data for atoms that have only one electron such as H, He^+, Li^{++}, etc. As photons are absorbed, the orbiting electron will jump from an inner orbit to one further from the nucleus. When the electron jumps back from the outer orbit to the original inner orbit, a photon of the same energy will be emitted.

Classical Forces at Play

The classical mechanical forces at play within a hydrogen atom are the gravitational force and the electrostatic (Coulomb) force.

The gravitational force for ^{1}H can be computed using Newton's Law of Gravitation:

$$_GF_r = \frac{Gm_pm_e}{r^2} \tag{2}$$

Where $_GF_r$ is the gravitational force at distance r from the nucleus, G is the Gravitational Constant, and m_p and m_e are the masses of the proton[1] and the electron. It is easy to show that the gravitational force is about 3.6E-47 N (Newtons) at the radius of Electron Quantum Level (EQL) 1 (5.29E-11 m)[2] and declines outward from there according to Eq. (2).

The electrostatic force for ^{1}H is given by Coulomb's Law:

$$_CF_r = \frac{Cq_pq_e}{r^2} = \frac{Cq^2}{r^2} \tag{3}$$

[1] Consistent with the treatment in reference [1], m_p is the mass of the proton less quarks.
[2] Computed using the reduced mass of the electron as discussed below.

where ${}_{C}F_{r}$ is the gravitational force at distance *r* from the nucleus, C is the Coulomb's Constant, q_p = q_e = q is the elementary charge, and *r* is the distance between them. It is easy to show that the electrostatic force is about 8.2E-8 N at the radius of EQL 1 and declines from there. This is enormously more powerful than the gravitational force at the same distance.

Quantum Energy

We call the energy absorbed to move up (or emitted when moving down) between two adjacent energy levels the quantum transition energy, or quantum energy for short. This is well-known to be determined in hydrogen by the Rydberg formula:

$$ {}_{Q}E_{n_1}^{n_2} = \frac{ch}{\lambda} = chR_H\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) \tag{4} $$

Here, ${}_{Q}E_{n_1}^{n_2}$ is the quantum energy absorbed on transition between n_1 and n_2 where $n_2 > n_1$ (or emitted if $n_1 > n_2$), *c* is the speed of light, *h* is the Planck constant, λ is the wavelength of the photon absorbed or emitted, and R_H is the Rydberg constant for 1-Hydrogen. We will restrict our attention to the case where $n_2 = n_1+1$. To move from quantum level 1 to quantum level 2, 1.63401E-18 Nm of energy are needed[3], which declines to 5.11050E-21 Nm going from level 9 to level 10.

Classical Analysis

The degree to which the equations of orbital mechanics—derived from careful measurements of the orbits of celestial bodies—apply to the orbits of electrons around the nuclei of atoms. In the latter case, the role of gravitation is replaced by the Coulomb (electrostatic) forces between the protons in the positively charged nucleus and the orbiting electron. (The gravitational force is also at work in the atom, but is so much smaller than the electrostatic force (by a factor of 10^{40}) it is almost always ignored.)

In orbital mechanics the total energy of an object in a circular orbit is the sum of potential energy and kinetic energy [4]. The potential energy of an orbiting body starts out with a small negative value and gets closer to 0 (i.e., increase) as the orbital radius increases. For the electrostatic force the formula for the potential energy, ${}_{C}^{U}E$, is

$$ {}_{C}^{U}E = -Cq^2/r \tag{4} $$

in Nm. The kinetic energy due to the angular rotation of the orbiting electron is given by

$$ {}_{C}^{K}E = \frac{Cq^2}{2r} = -\frac{{}_{C}^{U}E}{2} \tag{5} $$

The total Coulomb energy ${}_{C}^{T}E$ is therefore

$$ {}_{C}^{T}E = {}_{C}^{U}E + {}_{C}^{K}E = {}_{C}^{U}E + \frac{{}_{C}^{U}E}{2} = \frac{{}_{C}^{U}E}{2} = -\frac{Cq^2}{2r} \tag{6} $$

[3] We arbitrarily limit precision to 5 digits for brevity. This is the precision to which the radius of the proton is currently known.

Moving from an orbit n to an orbit n+1 causes a change in total energy given by

$$\Delta_C^T E_n^{n+1} = \left(\frac{Cq^2}{2r_{n+1}} - \frac{Cq^2}{2r_n}\right) \tag{7}$$

Simplifying and using (1) this becomes

$$\Delta_C^T E_n^{n+1} = \frac{Cq^2}{2r_1}\left(\frac{1}{(n+1)^2} - \frac{1}{n^2}\right) \tag{8}$$

This is just the negative of Eq. (4). This is as expected from the equations of orbital dynamics. The Rydberg value (4) is the amount of energy absorbed by the electron, which is turned into kinetic energy to raise the electron from level *n* to level *n+1*. At the same time, this is equal to the loss of kinetic energy by the orbiting electron as it moves from the higher angular velocity of orbital *n* to the lower orbital energy of orbital *n+1*. In general in orbital mechanics the energy needed to change orbits does equal the energy lost in the reduction of the angular velocity in the higher orbit. Meanwhile the potential energy of the electron in orbital 2 (compared to its earlier value in orbital 1) is decreased by the sum of these two: the gain in kinetic energy from the photon and the loss in kinetic energy by the reduction in orbital angular velocity.

Everything we have discussed is classical mechanics: properties of orbital mechanics well-known to Bohr. The departure from classical mechanics is only that orbitals are related to each other by Eq. (1) having only integer *n*: *n* cannot assume non-integral values.

In The New Physics model, we started with the hypothesis that inserting a particle into space displaces rather than replaces space [1]. This causes space to fracture spherically in what we call nuclear quantum levels, giving rise to gravitation (and inertia [5].) These nuclear quantum levels start near the nucleus starting with radii on the order of 10^{-15} m.

We extend this model by assuming that inserting a charge into space also spherically fractures space, but on a different scale: the electron quantum levels. Electron quantum levels start with radii around 10^{-11} m.

The notion that introducing a charge into space has an impact on space itself was probably not considered a century ago. The Michaelson-Morley experiment seemed to have demonstrated that space was indeed not a medium in which light waves propagated: it was nothing. This ignored the fact that the speed of light in space is determined by its permeability and permittivity, just as is the case with other transparent materials. In any case, the physics community evolved the notion that electrons were in a superposition of a particle state and a wave state, and that the only explanation of the Bohr model was, effectively, that the wave could only be a standing wave at the orbital distances governed by Eq. (1), so those were the only radii at which electrons could persist.

This has often been interpreted to mean that electrons simply leap somehow instantaneously from one orbital to the next, or at minimum travel nearly instantaneously in a straight line as illustrated in Figure 2.

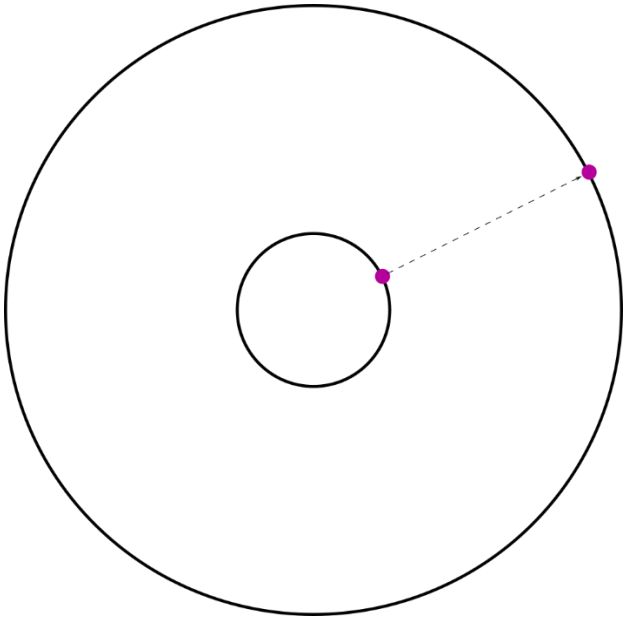

Figure 2. The quantum mechanical view of electron transition from orbital 1 to orbital 2 (drawn to scale, nucleus too small to show.)

When a body orbits another body and the mass of one is not negligible, they are really orbiting each other about the center of mass. The reduced mass of the electron, μ, is

$$\mu = \frac{m_e m_p}{(m_e + m_p)} \tag{4}$$

"Since the reduced mass of the electron-proton system is a little bit smaller than the electron mass, the reduced Bohr radius is slightly larger than the Bohr radius." [2]

$$Bohr\ radius = 5.29177E-11$$

$$"Reduced"\ Bohr\ radius = \ r_1 = 5.29462E-11$$

Both radii are expressed in meters. We use the latter since it is more accurate, and use Eq. (1) to find the radii of the outer orbitals.

The electron is orbiting the nucleus at quite a high speed. The formula for the angular velocity is

$$_C\omega_n = \frac{n\hbar}{\mu\, r_n^2} \tag{9}$$

Here, *n* is the electron quantum level number, $\hbar$ is the reduced Planck constant (the Planck constant divided by 2π), and r_n is the "reduced" Bohr radius of orbital *n*. For orbital 1, the angular velocity is 4.13189E16 radians/s, or (multiplying by the radius) 2.18769E6 m/s. For orbital 2 this is 1.09385E6 m/s, or about 1,000 km/s. If the electron is in any way a particle, it is simply unlikely that the electron can make an abrupt, 90° transition and pop to the next quantum level as illustrated in Figure 2. This is where the advocates of quantum mechanics will tell you physics is not supposed to make sense. Seriously?

What might the real path of the electron be? The most efficient way to transfer from one orbit to another is called the Hohman transfer [7].

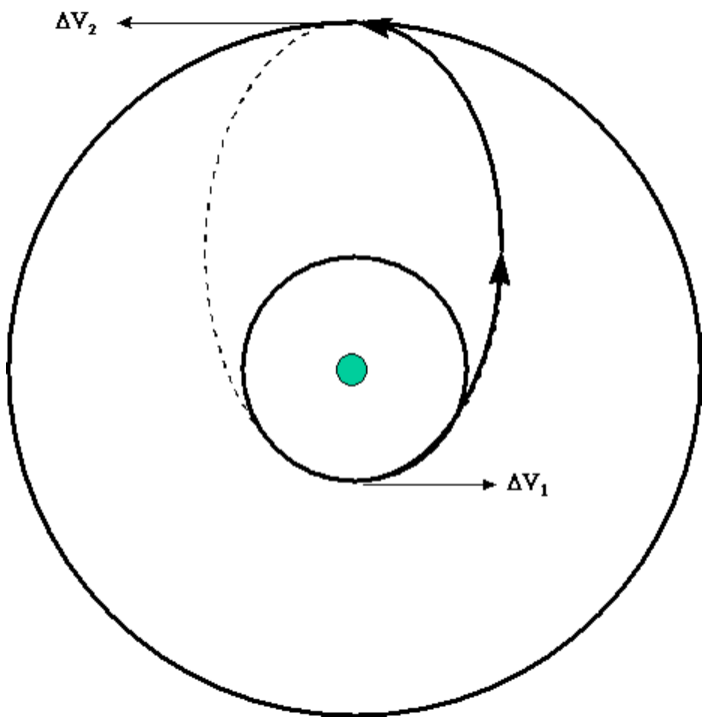

Figure 3. Hohman transfer from an inner circular orbit to an outer circular orbit using an elliptical transfer orbit [7]. (Source: *Astronomical Returns, 2023*.)

Nature has a way of being inherently efficient, so it tempting to assume this is the path an electron might take in transitioning from one orbital to the next and back again. The problem with this model, however, is that two bursts of acceleration are required to effect a Hohmann transfer: one at the start to enter the elliptical transfer orbit, and one at the end to transition to the outer circular orbit. (This is true also if the starting and destination orbitals are elliptical.)

It is a little bit difficult to imagine the absorption of a photon of energy occurring in two distinct phases as required by a Hohmann transfer. There are other possible transitions, see [7] for details. But all but one of them require multiple bursts of acceleration.

Spiral Transfer

The only way to transfer orbits under a continuous absorption of energy is the spiral transfer. The number of revolutions will determine the transfer time between the orbitals if the radial velocity is constant. This may not be an accurate assumption but can serve as a starting point.

We have created a simulation of such a transfer with the number of revolutions as a parameter. Constants used in the simulation are listed in the Appendix.

We set as a parameter whether the electron is transitioning from orbital 1 to orbital 2, or the reverse. To simplify the discussion, we will just assume the former. We set the starting radius to the radius of orbital 1 (the Reduced Bohr radius) and the stopping radius to that of orbital 2 as determined by Eq. (1). The initial and final velocities are set to the values noted above.

The simulation is set to increment in (arbitrary) time steps of 1E-20 seconds. To prevent looping due to some simulation error, maximum steps are set to 50,000,000, which limit should not be reached.

At the outset, the angle of the electron in its orbit is arbitrarily set to 0. The period of each orbital is the inverse of {the angular velocity in radians/s as given in Eq. (9) divided by 2π}. These are for orbital 1 = 1.52066e-16 s and for orbital 2 = 1.21653E-15 s.

Total time for the transition is then estimated by averaging these two periods and multiplying this average by the number of revolutions parameter supplied.

The velocity of transition is then computed as the distance between the radii divided by the estimated time for transition.

We need only provide a function that simulates each step. This function takes three parameters: the current radius of the electron, its current angular displacement, and its rate of angular displacement. It increments the radius by the {velocity of transition by the time step}. It increments the angle of rotation by the product of the rate of angular displacement times the time step. It returns the new radial position and angle of the electron.

It remains only now to loop until we reach the new orbital by calling the step function, then updating the angular velocity according to the new radius (using Eq. (9).)

If we assume it takes ten revolutions to transition from orbital 1 to orbital 2, this looks like Figure 4.

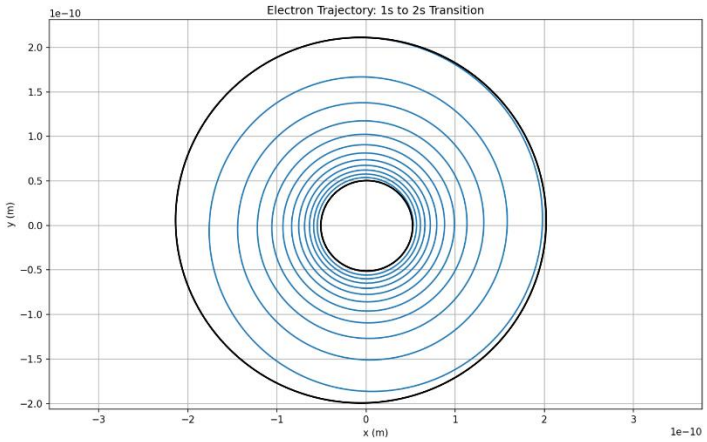

Figure 4. Simulated path of an electron transitioning from orbital 1 to orbital 2 in about 10 revolutions of the nucleus. A transition from 2 to 1 follows a similar pattern.

The time for this transition to take place is 6.84320e-15 s.

By contrast let's assume it takes the electron 100 revolutions to make the transition. The result is shown in Figure 5.

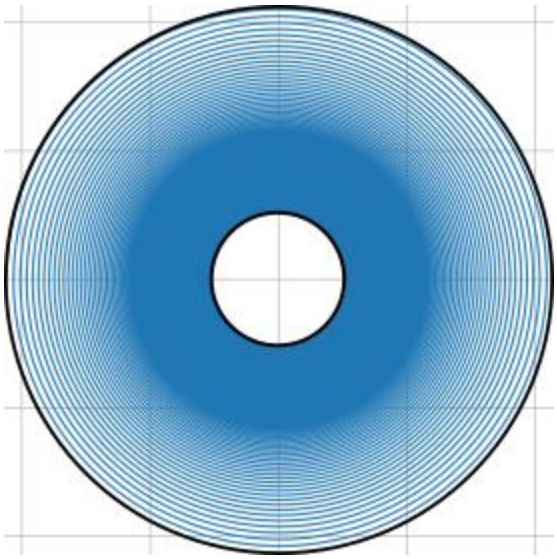

Figure 5. Simulated path of an electron transitioning from orbital 1 to orbital 2 in about 100 revolutions of the nucleus.

The time to transition in this case is 10 times the time taken by the path in Figure 4. Are these times reasonable?

It is not easy to measure the orbital transition time for an electron. It appears to be in the range of femtometers (10^{-15}) to picometers (10^{-12}). Times for both 10-revolution and 100-revolution transitions are in this range. More precise measurements are needed to determine the actual trajectory of the electron from one orbital to another. But we remain confident that it is not a straight line.

Conclusion

We have taken a close look at what path might be followed by an electron transitioning from one orbital to another. We have questioned the proposition that this is either a straight line at right angles to the orbits, or that it is somehow "instantaneous". We have put forth the hypothesis—based on classical orbital mechanics—that this might be a spiral path. More precise measurements are needed to determine the actual time of transition and number of revolutions of the nucleus required to effect the transition.

Appendix

Constant	Value	Units
Coulomb's constant	8.98755e9	Nm^2/C^2
Electron mass	9.10938e-31	kg
Proton mass	1.66340e-27	kg
Reduced Bohr radius	5.29465e-11	m
Planck constant	6.62607e-34	Ns
Reduced Planck constant	1.05457e-34	Ns
Photon energy	10.19868	eV
Period orbital 1	1.52066e-16	s
Period orbital 2	1.21653E-15	

References

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