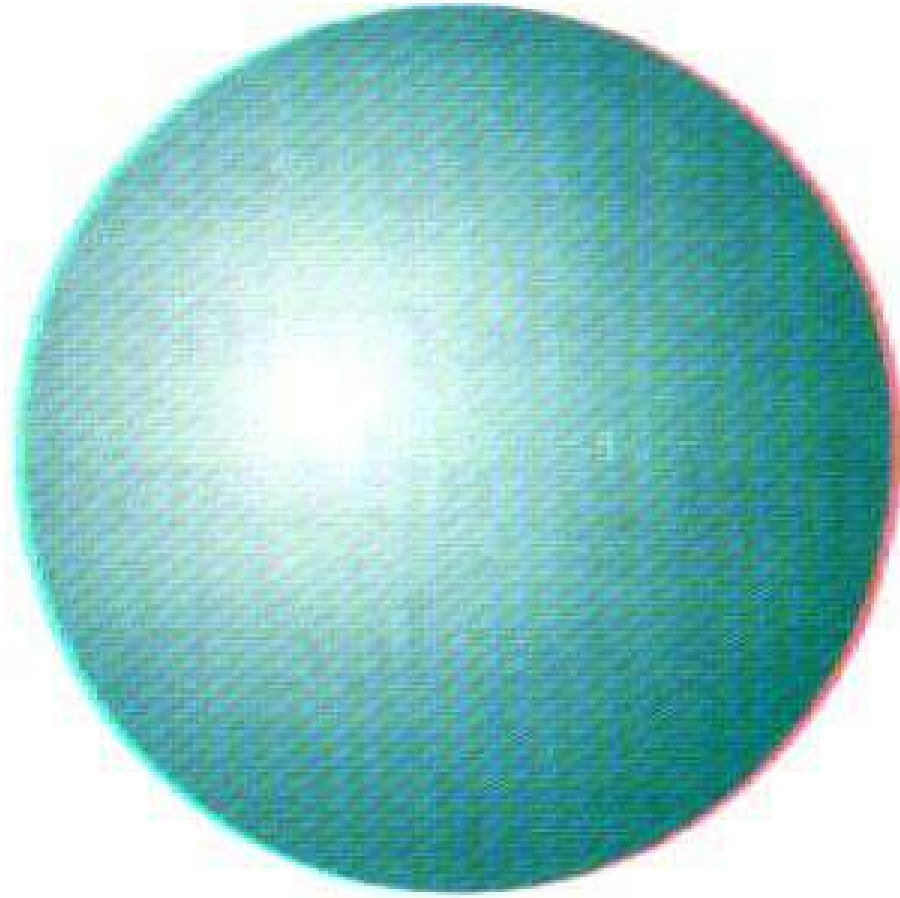


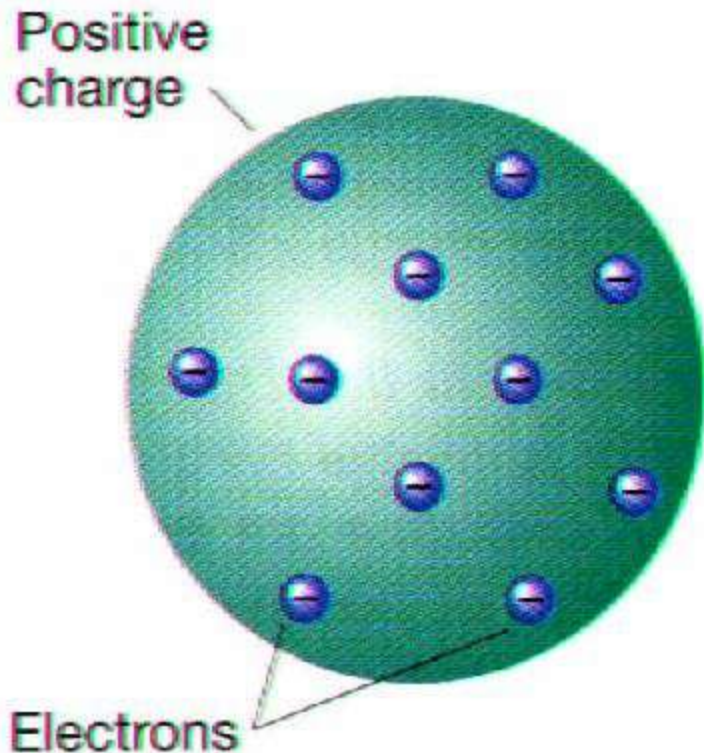
Chapter 5

The Electron Cloud

Dalton's Model

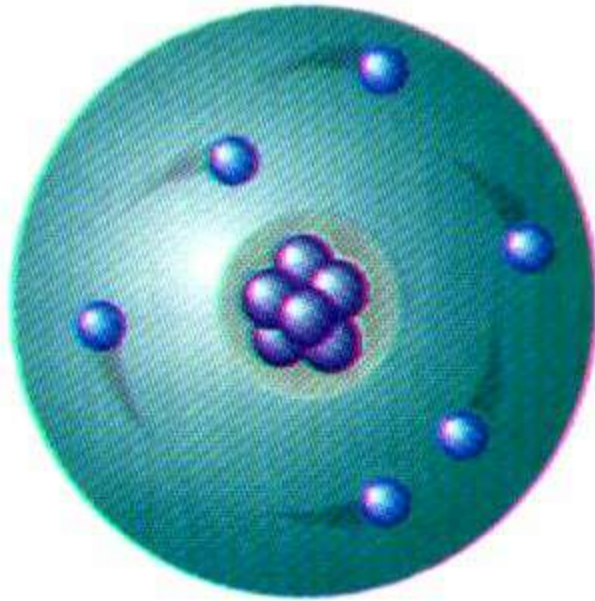


Thomson's Plum – Pudding Model



- positive sphere (pudding) with negative electrons (plums) dispersed throughout.

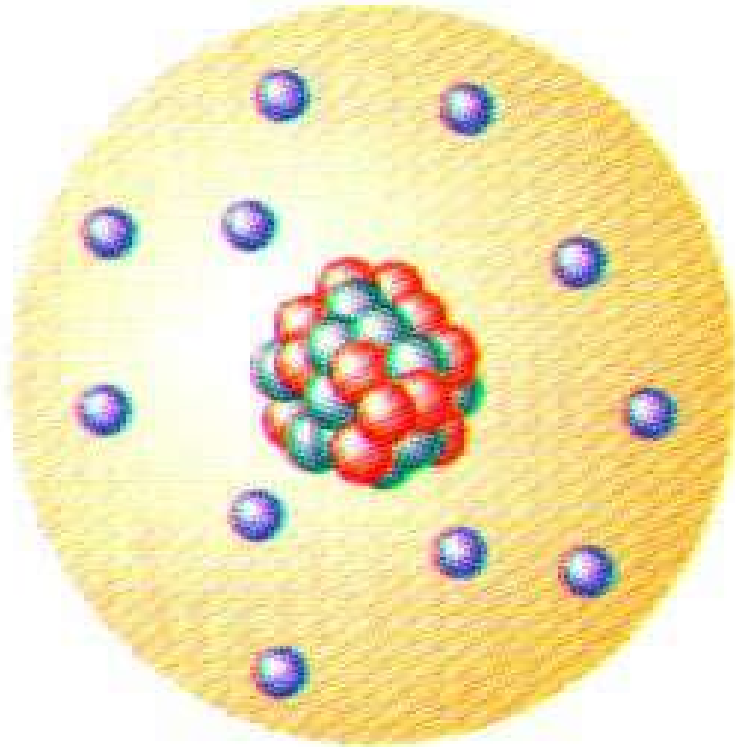
Rutherford's Nuclear Atom (The Planetary Model)



 proton $+$

 electron e^{-}

Chadwick's Revision



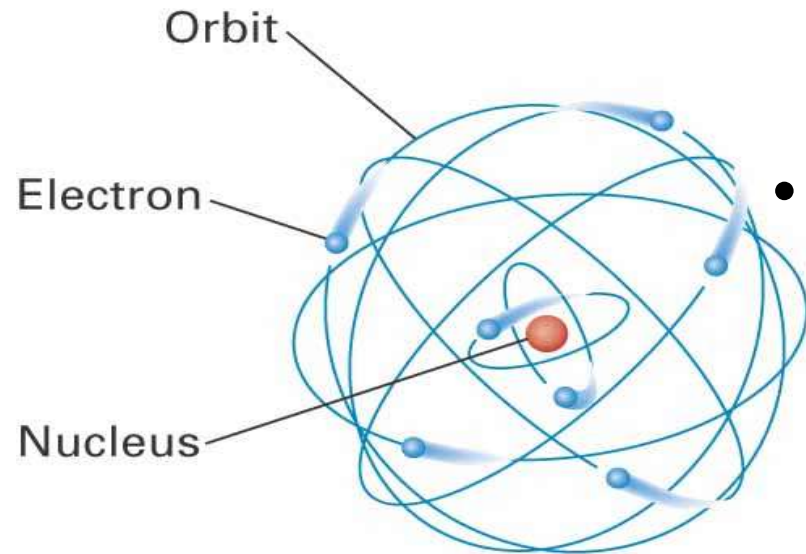
 proton

 neutron

 electron

Overall charge = 0

Bohr Model

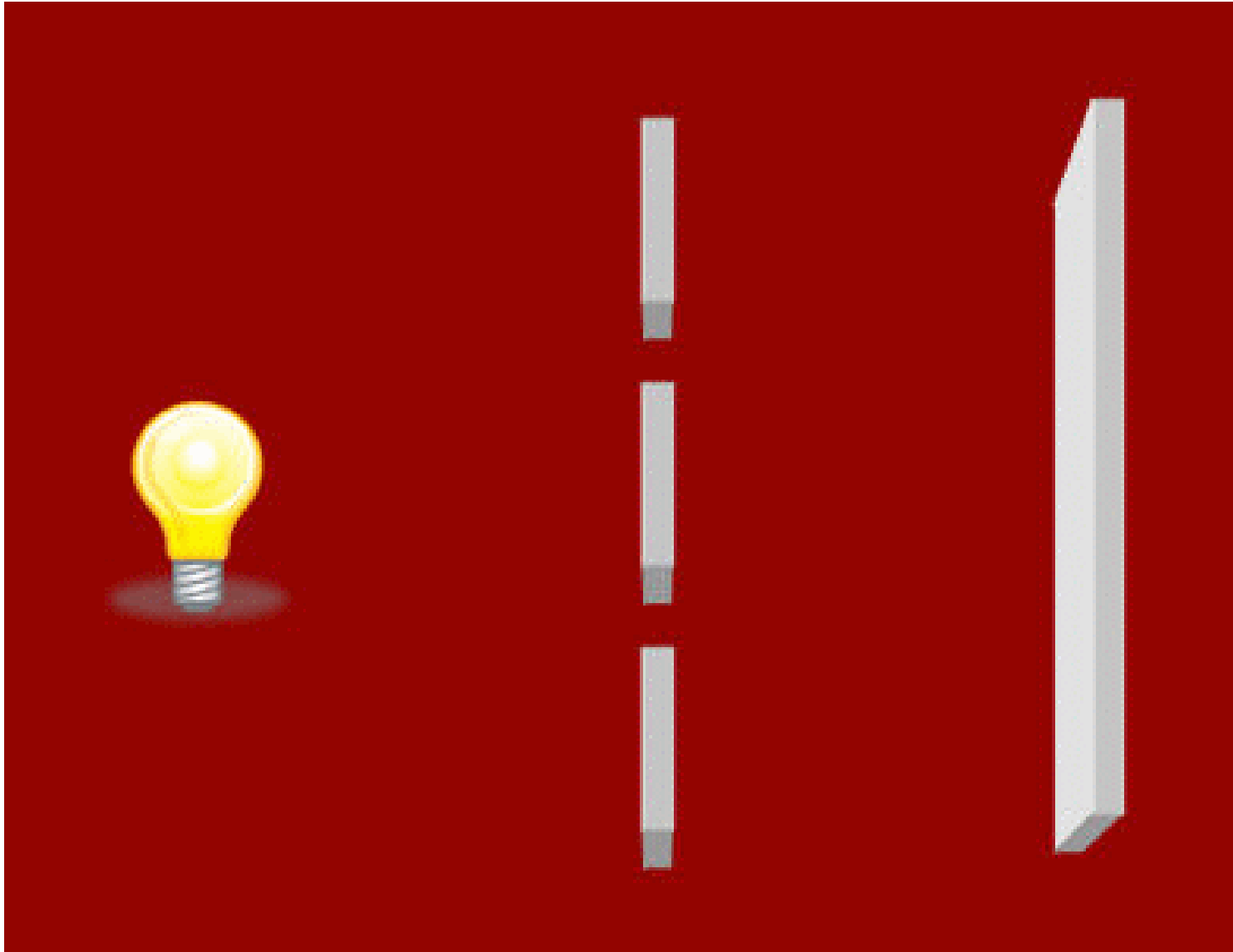


- **Electrons move around the nucleus in orbits of definite energies.**
- **The energy of the orbit is related to its distance from the nucleus. The lowest energy is found in the orbit closest to the nucleus.**
- **Radiation is absorbed or emitted when an electron moves from one orbit to another.**

The Nature of Light

- Physicists who studied light in the 1700s and 1800s were having a big argument about whether light was made of particles shooting around like tiny bullets, or waves washing around like water waves.
- There is evidence to support both views but scientists thought that you had to be on one side of the issue or the other. That one view was right and the other was wrong. Thus the big argument.

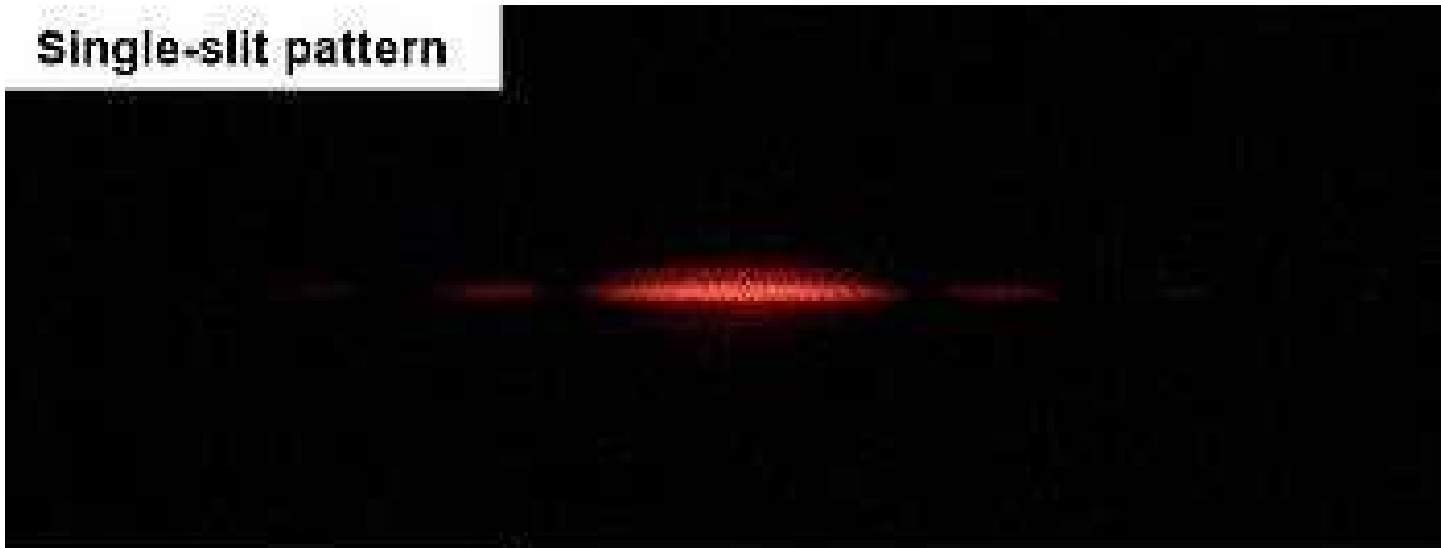
Wave Particle Duality



Wave – Particle Duality

- Light can act like a particle

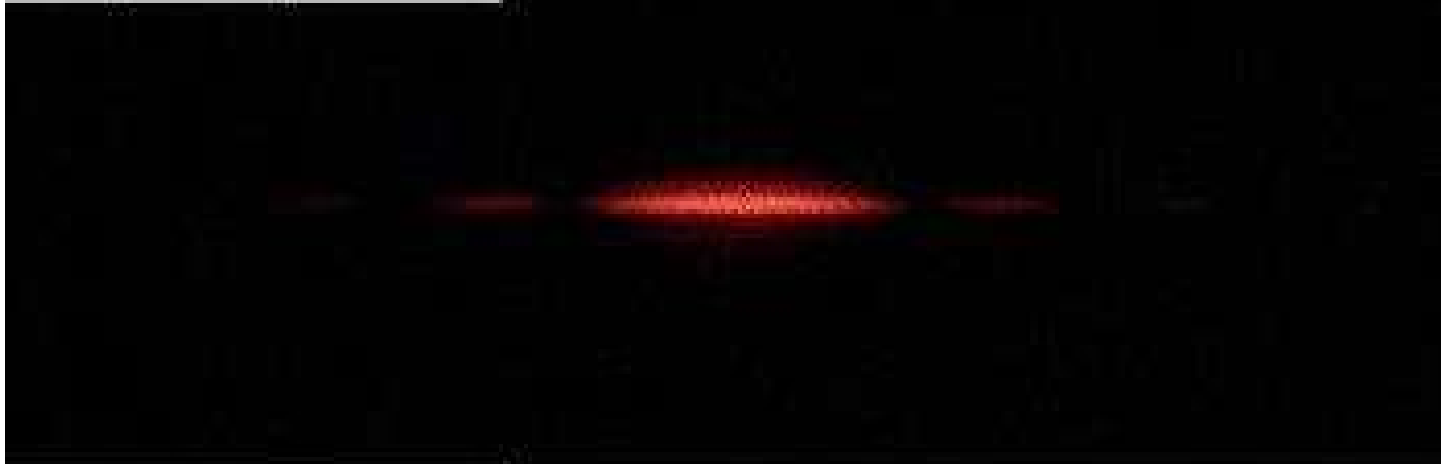
Single-slit pattern



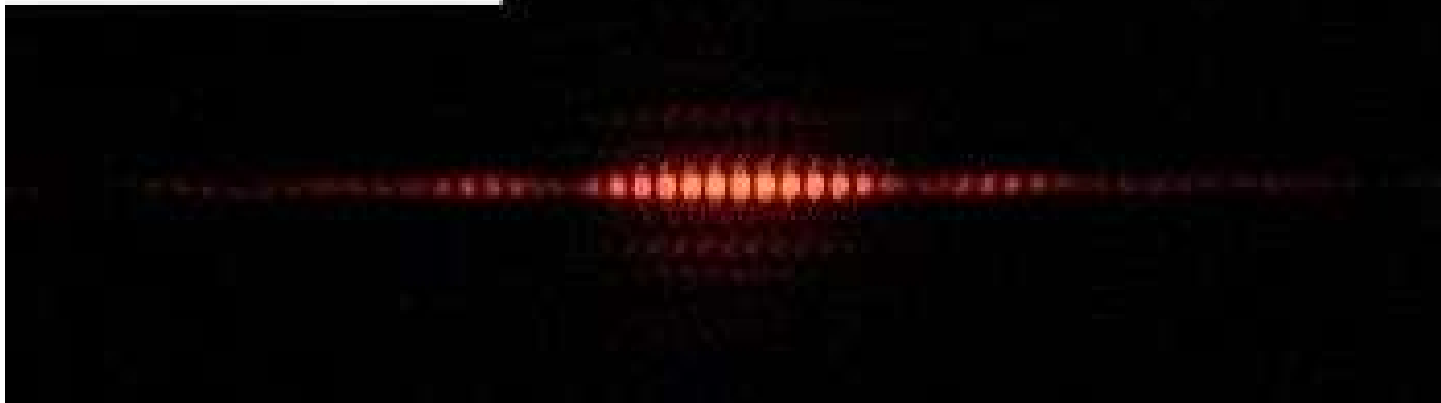
Wave – Particle Duality

- Light can act like a wave.

Single-slit pattern



Double-slit pattern



Electrons are like light



Louis de Broglie
(1892-1987)

1929 Nobel Prize for mathematically identifying the wave nature of matter (wave-particle duality)

- **In 1924, the French scientist Louis de Broglie wondered that since light, normally thought to be a wave, could have particle properties, could matter, specifically the electron, normally thought to be a particle, have wave properties as well?**

Wave – Particle Duality

- Today, these experiments have been done in so many different ways by so many different people that scientists simply accept that both matter and light are somehow both waves and particles.
- Although it seems impossible to understand how anything can be both a wave and a particle, scientists do have a number of equations for describing these things that have variables for both wavelength (a wave property) and momentum (a particle property). This seeming impossibility is referred to as the **wave-particle duality**.

Wave – Particle Duality

- DeBroglie, Einstein (and others) showed that electromagnetic radiation has properties of matter as well as waves. This is known as the **wave-particle duality for light**.
- Wave-particle duality is perhaps one of the most confusing concepts in science, because it is so unlike anything we see in the ordinary world. Scientists generally admit that even they do not fully understand how this can be, but they are quite certain that it must be true.

The Heisenberg Uncertainty Principle



The Uncertainty principle

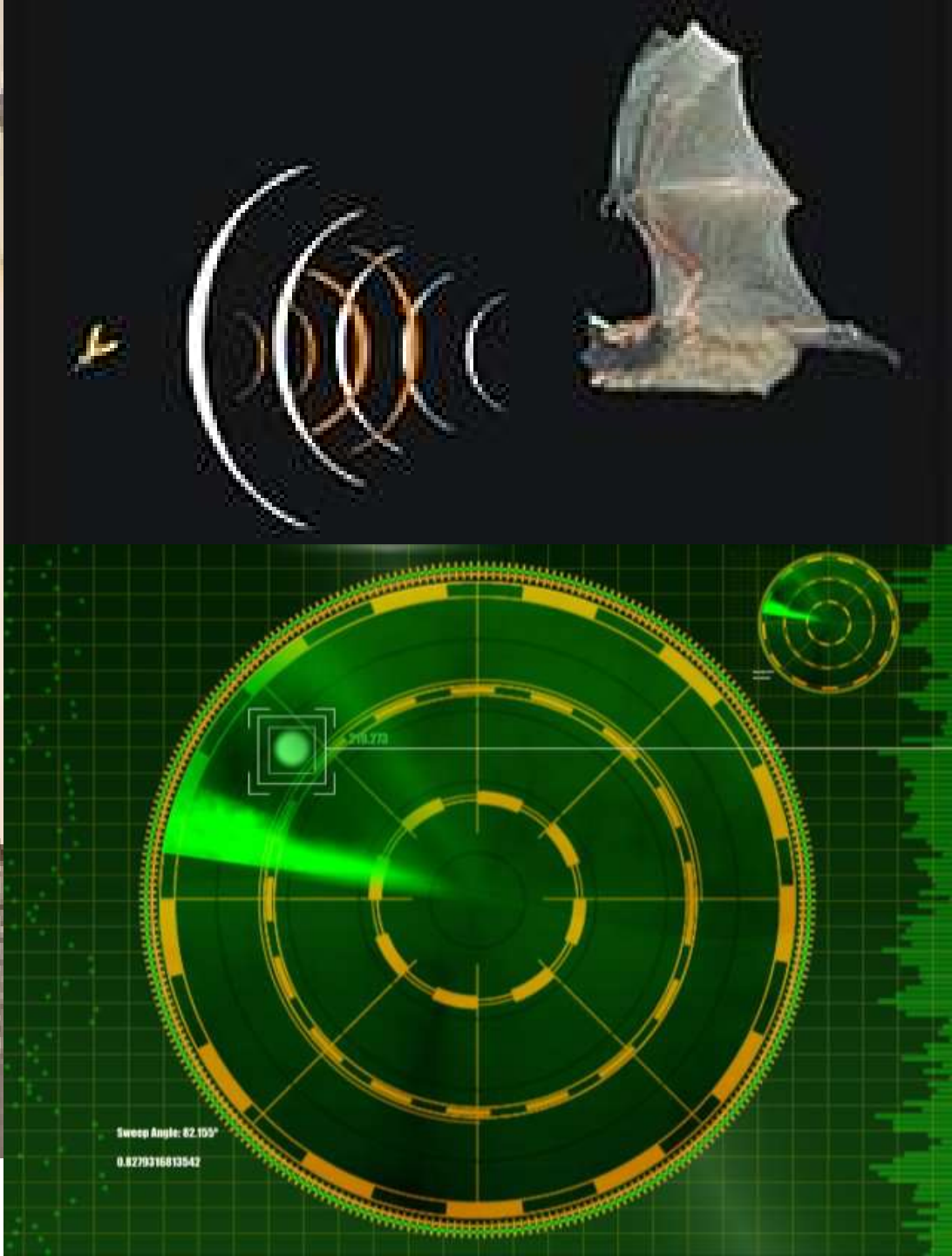
- **If an electron really could exist as a wave inside the atom, where exactly was it?**
- **The German scientist Heisenberg determined that it was impossible to experimentally determine both the position and the speed of the electron at the same time.**
- **This became known as the Heisenberg Uncertainty Principle.**
- **It simply means that the electron is so small and moving so fast, that the simple act of trying to measure its speed or position would change either quantity.**

How do we see something?

How do we see something?



Smack

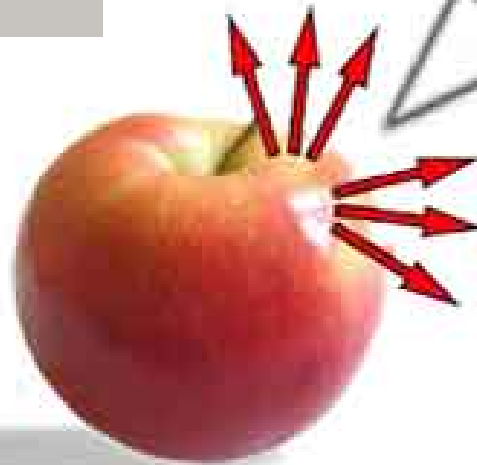


Electromagnetic
Spectrum



"white
light"

Light



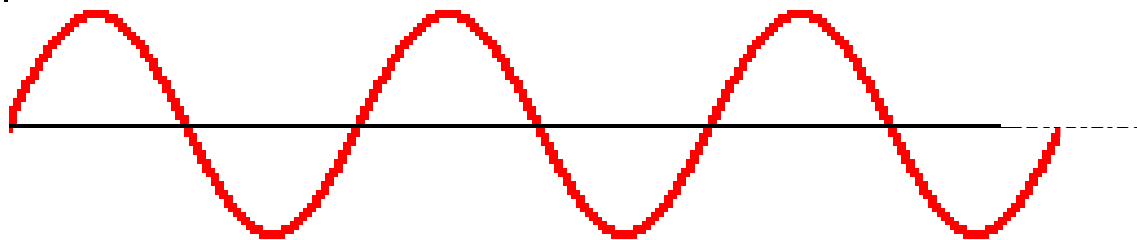
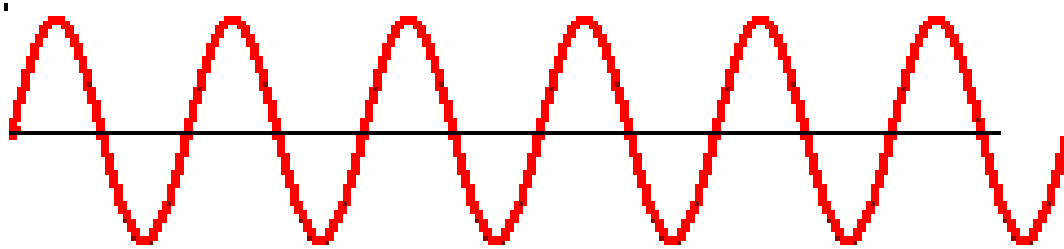
The Uncertainty principle

- **Trying to detect the electron by shining some type of wave at the electron would be energetic enough to move it and thus change its position or speed.**
- **So we are out of luck finding exactly where the electron is in the atom.**
- **We can see that this principle would only apply to extremely small particles. If we shine a flashlight at a truck in the dark, we can surely tell its position, or if we want to determine its speed by radar (radio waves) we can do so. In each case, our measuring tool will not affect the speed or position of the truck; it is too massive.**

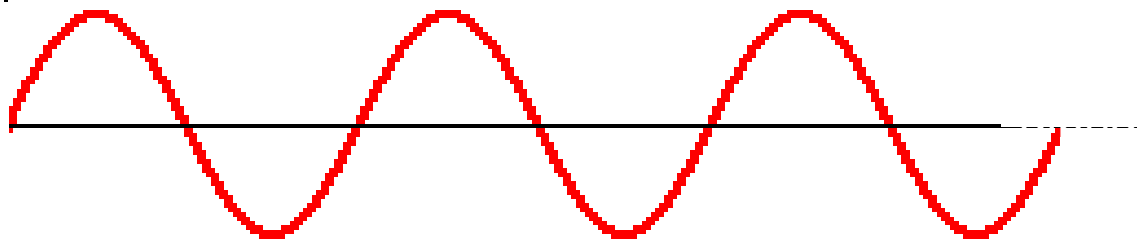
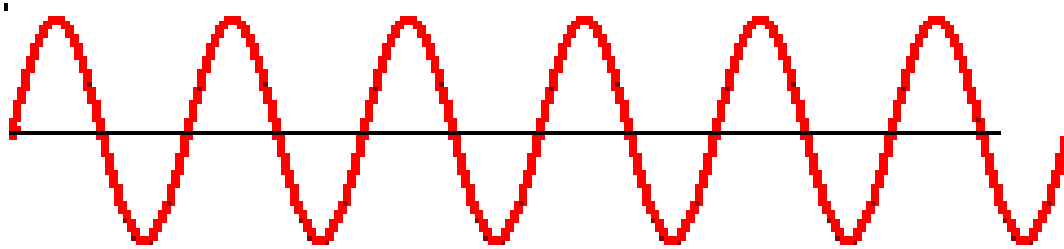
The Heisenberg Uncertainty Principle

- The more energy we hit the electron with the more we change it's momentum (velocity).

What energy should I use to “see”
the electron?



The higher energy wave gives a better estimate of location but changes the momentum (velocity) more. The lower energy wave will cause less of a momentum change but is a poor estimate of location.

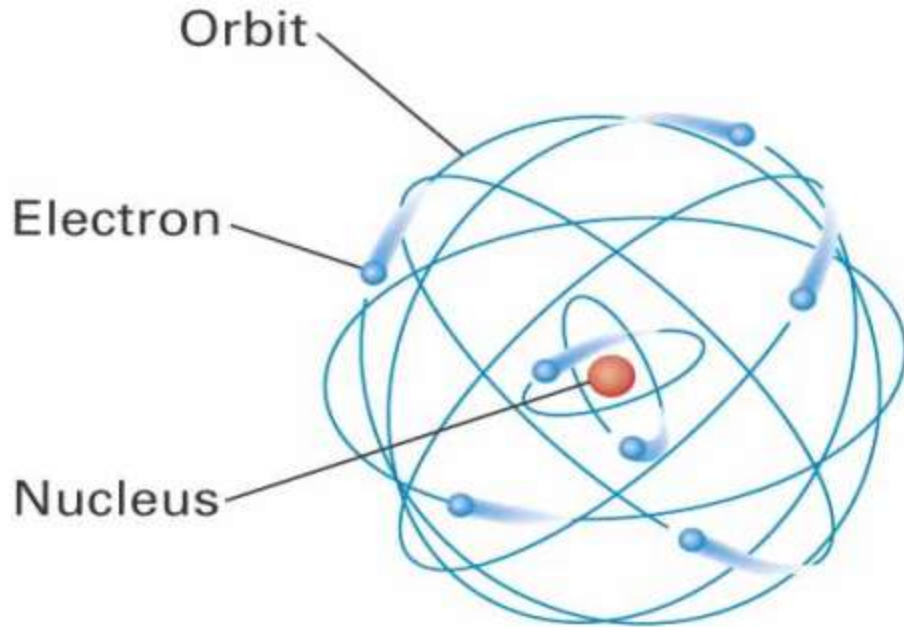


The Heisenberg Uncertainty Principle



- It is impossible to determine the exact position (location) and momentum (velocity) of an object at the same time.
- So Heisenberg argues that every measurement destroys part of our knowledge of a system that was obtained by previous measurements.

Problems with the Bohr Model



- It violates the Heisenberg Uncertainty Principle because it considers electrons to have known orbits.
- It makes poor predictions regarding the spectra of atoms larger than hydrogen.

Schrodinger



- The Austrian scientist, Erwin Schrödinger, pursued de Broglie's idea of the electron having wave properties and it seemed to him that the electron might be like a **standing wave** around the nucleus.

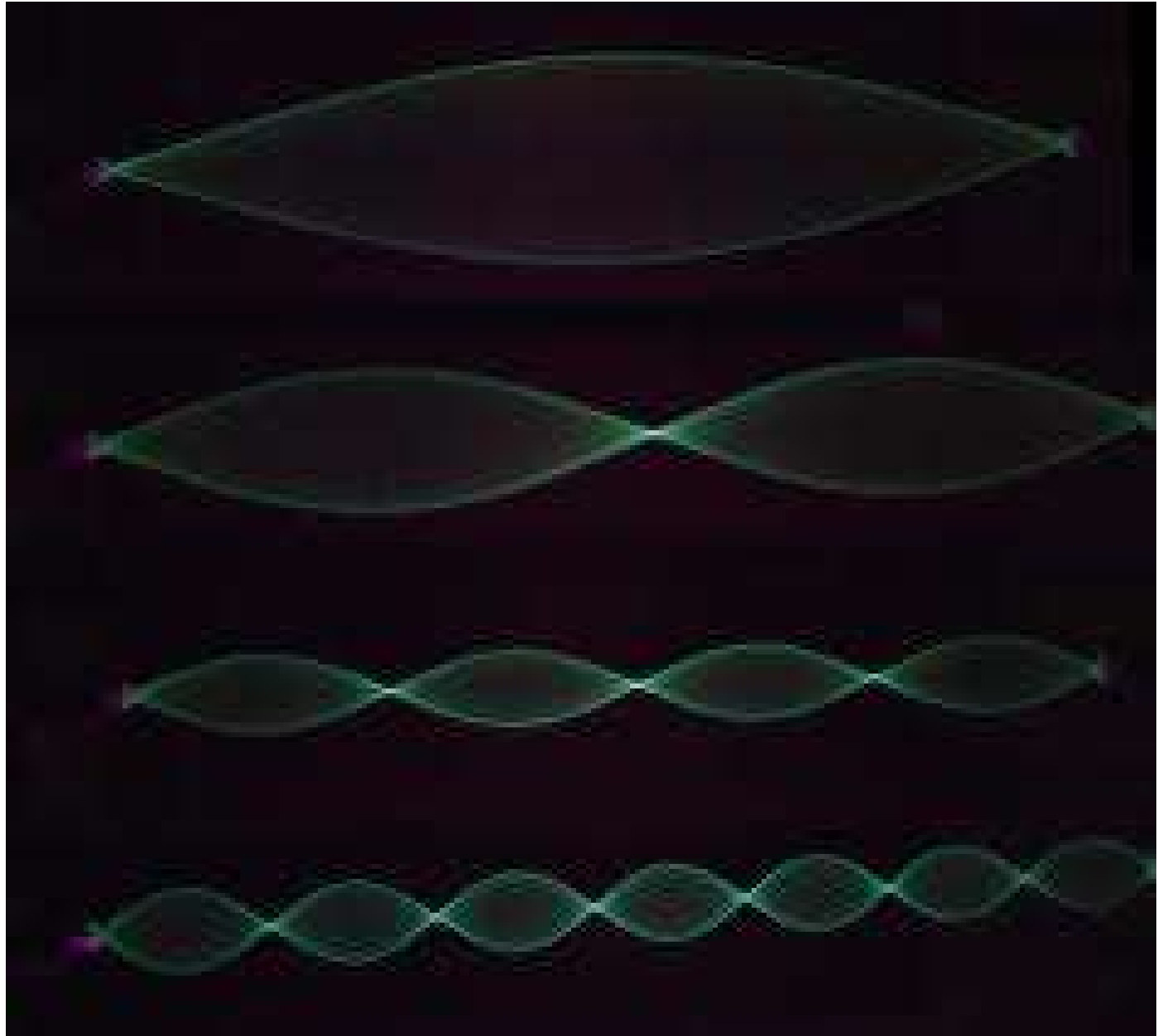
Standing Waves

- A standing wave is like a string stretched between two points and plucked, like a guitar string. The wave does not travel between the two points but vibrates as a standing wave with fixed wavelength and frequency.

Standing Waves

- There is a limitation on the number of waves that will fit in between the two points. There must be a whole number of waves to be a standing wave; there cannot be, for instance, a 2.3 waves. So, only certain, or allowed wavelengths (or frequencies) can be possible for a given distance between the 2 points.

Standing Waves



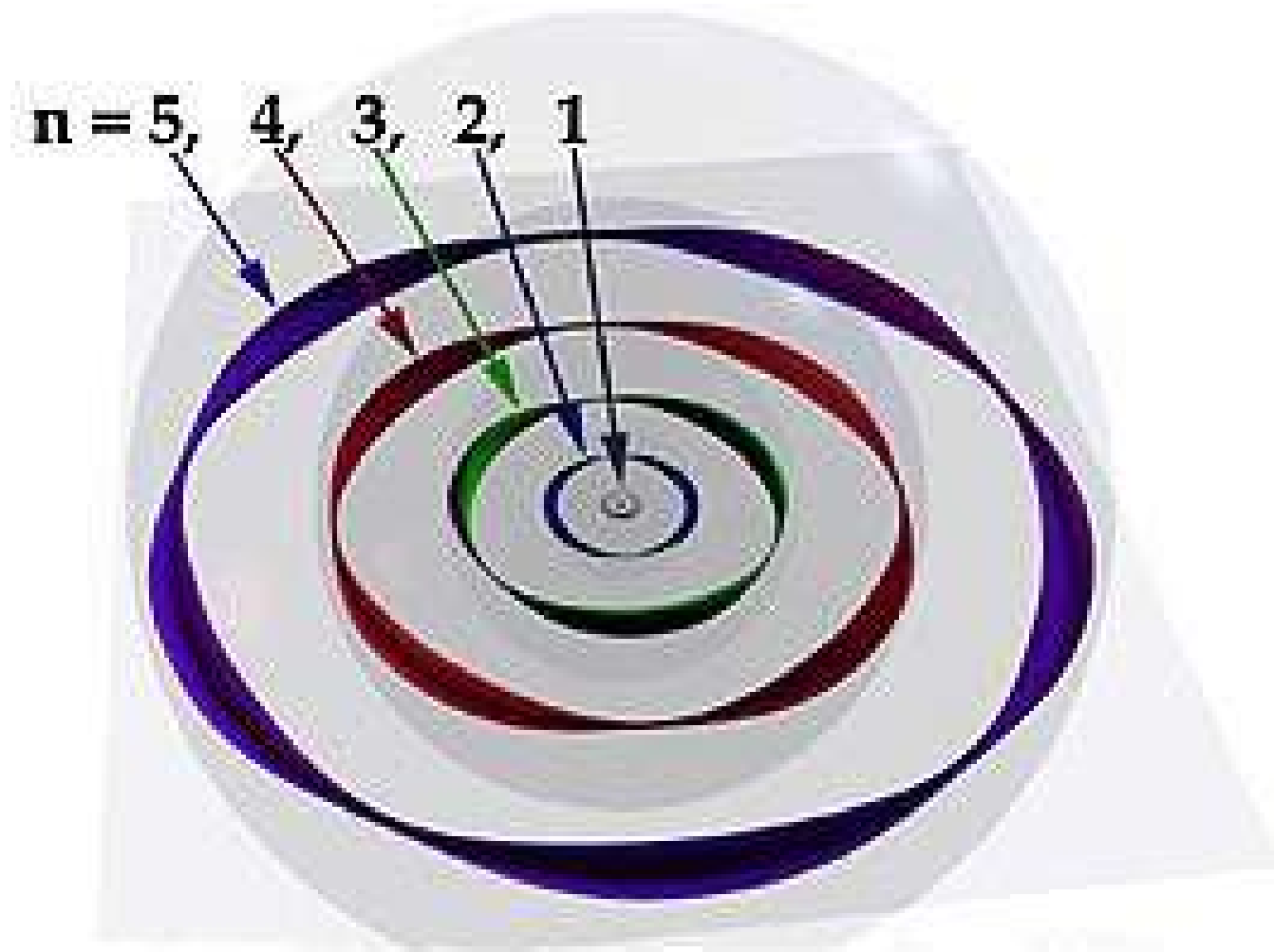
Standing Waves

- Schrodinger believed that the same standing waves existed in the atom.
- At any given distance from the nucleus, only a certain number of whole waves would “fit” around the nucleus and not overlap in between waves.

Standing Waves

- For a given circumference, only a fixed number of whole waves of specific wavelength would work.
- Most wavelengths (those that were not whole numbers) would not work and thus would not be observed.

Standing Waves



Schrodinger's Model

- This idea agreed very well with Bohr's idea of quantized energy levels: only certain energies and therefore, wavelengths would be allowed in the atom.
- This explained why only certain colors (wavelengths) were seen in the spectrum of the hydrogen atom.

Schrodinger's Model

- Schrodinger set out to make a mathematical model that assumed the electron was a standing wave around the nucleus.
- His solutions to that model agreed not only with the experimental evidence for hydrogen (as Bohr's did too), but gave excellent results for all atoms when compared to their actual spectrum.

Schrodinger's Equation

- Schrödinger's equation requires calculus and is very difficult to solve.

$$\frac{-\hbar^2}{2m} \frac{\partial^2 \Psi(x,t)}{\partial x^2} + U(x)\Psi(x,t) = i\hbar \frac{\partial \Psi(x,t)}{\partial t}$$

Schrodinger's Equation

- The important thing is that the solution of the equation, when treated properly, gives **not** the exact position of the electron (remember Heisenberg), but the **probability** of finding the electron in a specific place around the nucleus.

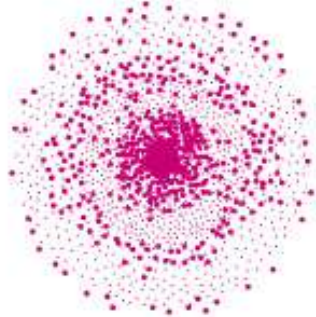
Schrodinger's Equation

- This most probable “place” is known as an **orbital**.
- An orbital is a volume space around the nucleus that contains the electron 90% of the time.
- Realize this space is determined from the solution of an equation and not from direct observation.

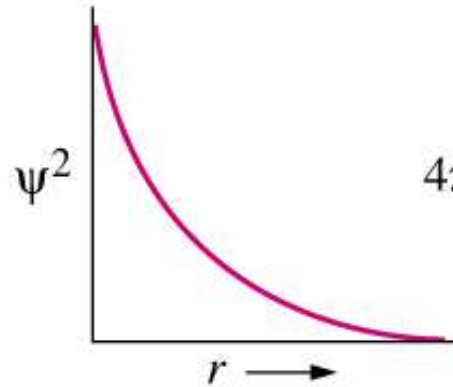
$$\frac{-\hbar^2}{2m} \frac{\partial^2 \Psi(x,t)}{\partial x^2} + U(x)\Psi(x,t) = i\hbar \frac{\partial \Psi(x,t)}{\partial t}$$



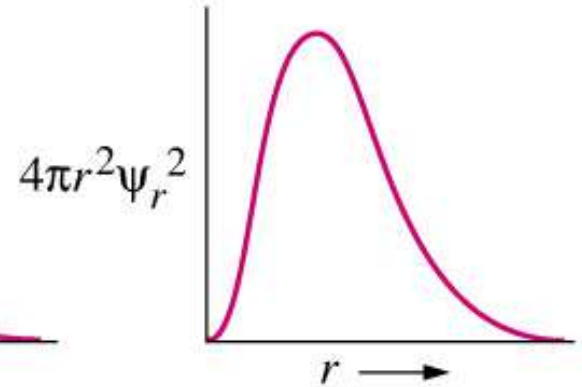
(a)



(b)



(c)



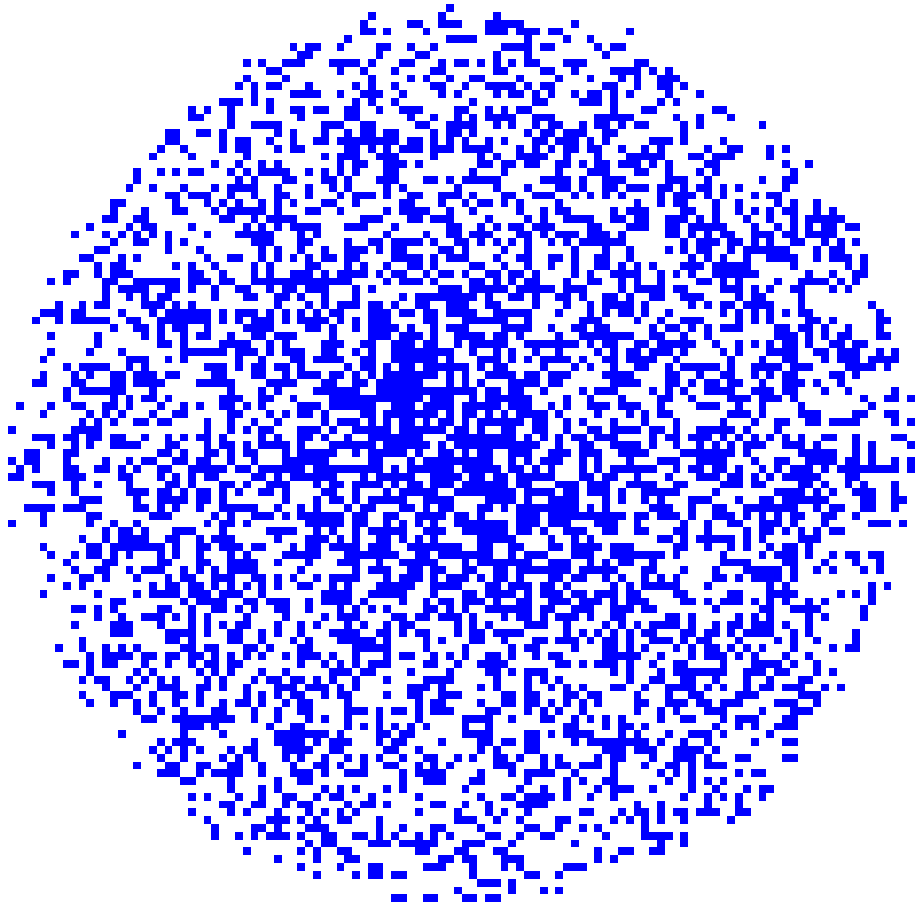
(d)

(a) 1s electrons can be "found" anywhere in this solid sphere, centered on the nucleus. (b) The electron density map plots the points where electrons could be. The higher density of dots indicates the physical location in which the electron cloud is most dense. (c) Electron density (Ψ^2) is shown as a function of distance from the nucleus (r) as a graphical representation of the same data used to generate figure b. (d) The total probability of finding an electron is plotted as a function of distance from the nucleus (r).

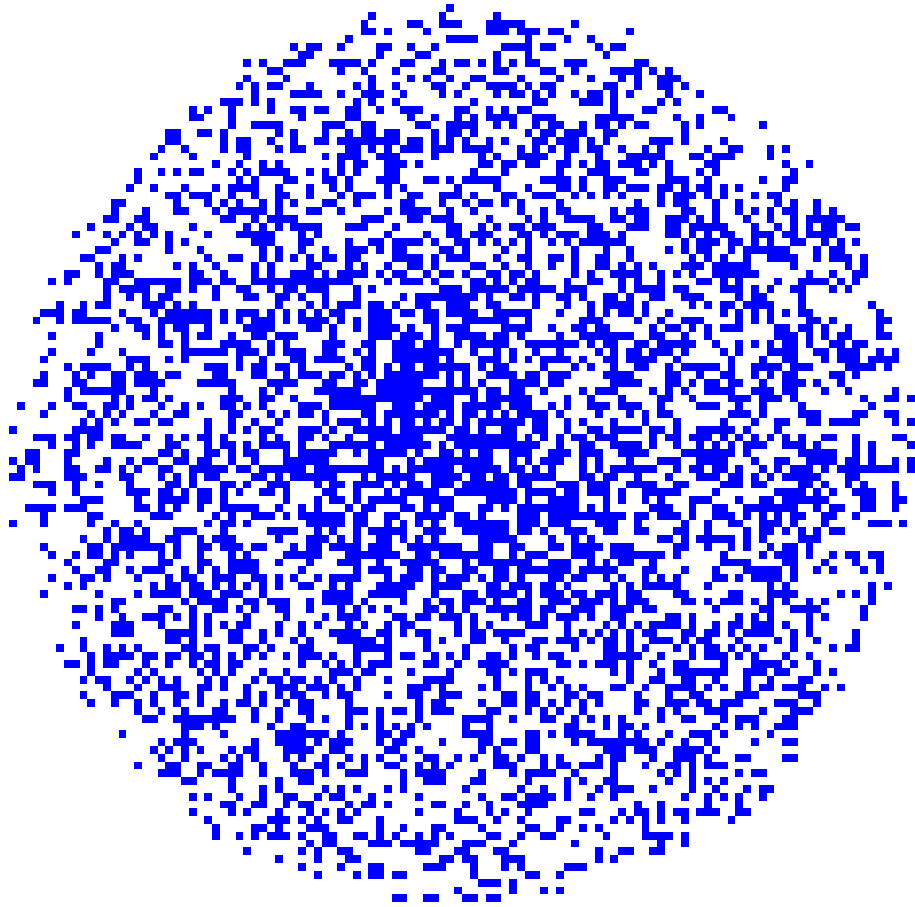
The Quantum Mechanical Model



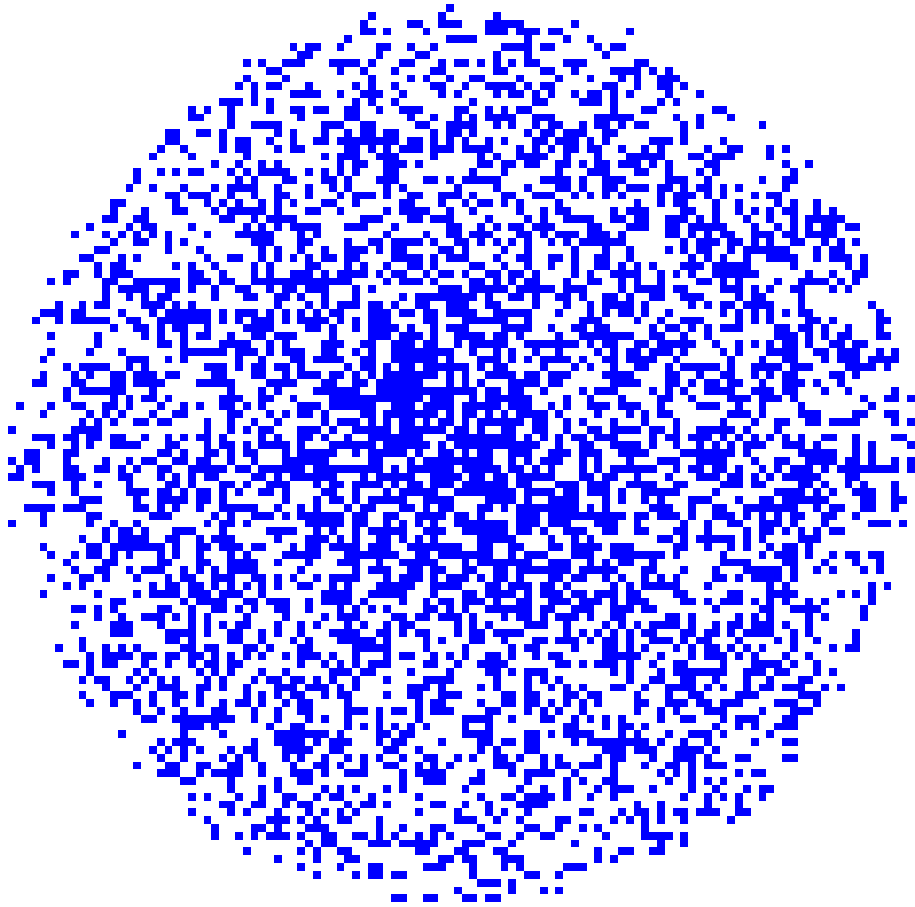
The Quantum Mechanical Model



“Electron Cloud” Model

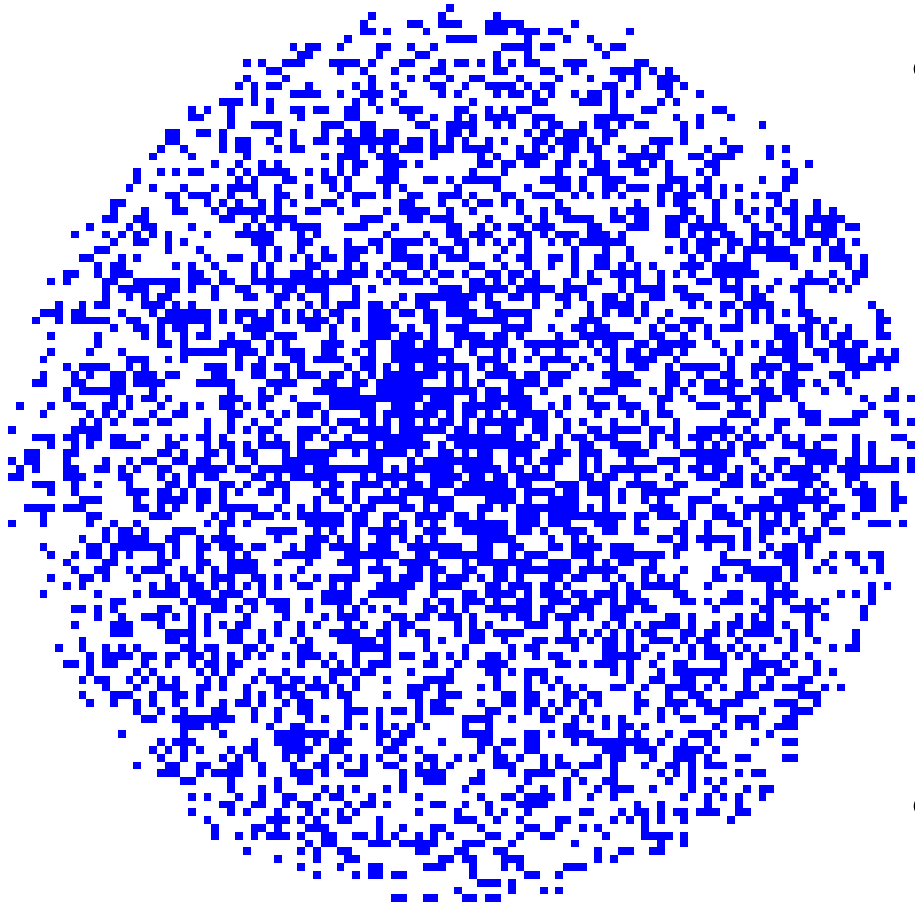


Electron Cloud Model



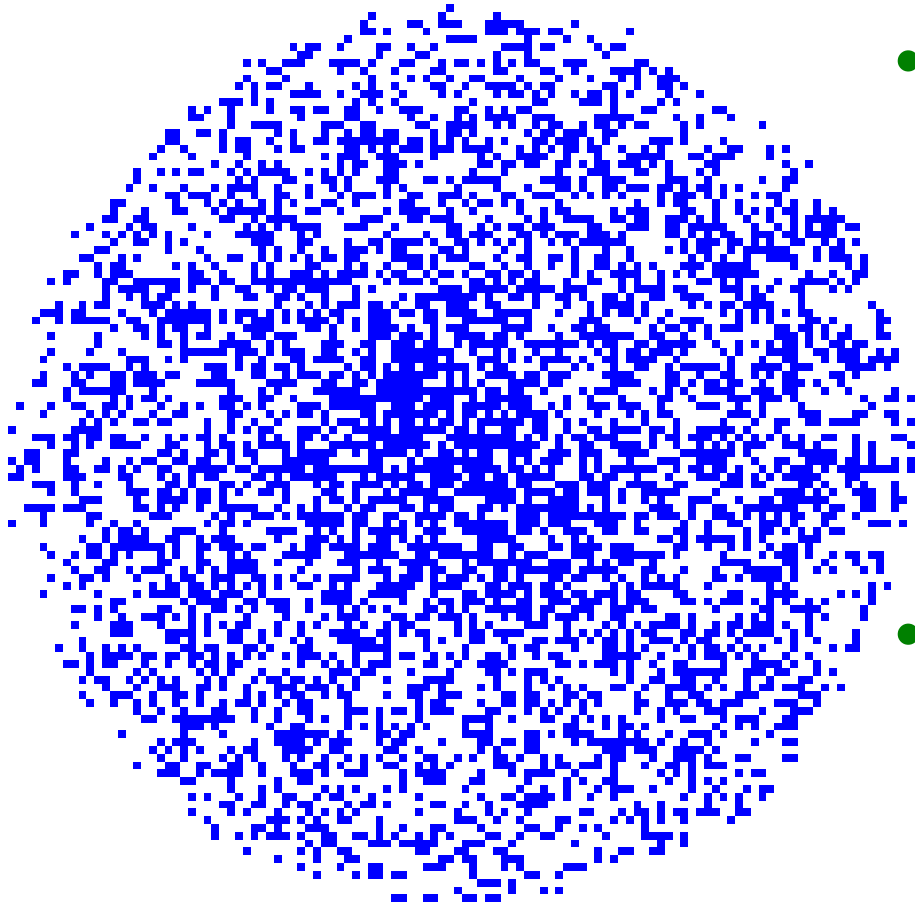
- Based on **probability**

Electron Cloud Model



- The **electron cloud** is a cloud of negative charge surrounding the nucleus that shows areas where an electron is “likely” to be found.
- **90% probability.**

Electron Cloud Model



- **The location of the electrons depends upon their energy which places them into a certain region of the electron cloud.**
- **Electrons with less energy are found closer to the nucleus.**