X-rays and atomic structure

Instead of using a diffraction grating, I can observe a diffraction pattern by shining a beam of X-rays through a crystal, for example NaCl.
Diffraction+interference

- Remember this experiment
- Shine a coherent light through one slit, and you see a diffraction pattern
- Shine a light through 2 slits and the waves diffract through each slit and the two waves interfere with each other producing the diffraction+interference pattern shown to the right
- …because the wavelength of the light is similar to the spacing between the slits and the slit width
What would happen if I replaced the light source by a stream of electrons which had a de Broglie wavelength the same as the coherent light source previously?

I would see the same diffraction pattern on the screen.

The electron would act like a wave and diffract when going through the slit so that if I were to count the distribution pattern for where the electrons hit, I would get the diffraction pattern shown.
Diffraction + interference

- ...and here’s the weird(er) part
- Let me put in two slits separated by a small distance and fire my electron beam
- Some of the electrons will go through the top slit and some through the bottom
- If I look at the screen and count where the electrons hit, I’ll see the same interference pattern as I would with a beam of light, even if I fire the electrons through the slits one at a time
- Somehow if an electron passes through the lower slit, it knows that there is an upper slit present as well
Demo

Electron microscope

- Looks somewhat similar to an optical microscope but accelerates electrons
- Wavelength of the accelerated electrons can be much smaller than that of visible light
- Therefore, can resolve smaller features
Images of a fly
Erwin Schroedinger

- Extended de Broglie’s ideas and introduced idea of a wave function \( y(x,y,z,t) \) that described behavior of particle as a function of position and time
- Probability of a particle being in a place \((x,y,z)\) at a time \(t\) is given by \( |y(x,y,z,t)|^2 \)
- We’ll find out later that it’s probability distributions that we have to talk about when dealing with subatomic systems, not classical concepts like orbits and trajectories
- An interesting connection
  - Schroedinger wrote an article titled “What is Life” in which he discusses the need for some mechanism for coding and transfer of genetic information from one generation to the next, i.e. DNA
  - Watson and Crick read this article and were inspired to try and find the structure of DNA
Werner Heisenberg

● German physicist who in the 1920’s was one of the founders of quantum mechanics

● Perhaps most famous for his uncertainty principle which related the precision with which you could measure complementary variables, like energy and time, or position and momentum
What is the Heisenberg Uncertainty Principle?

- …or
  - “The more precisely the position is determined, the less precisely the momentum is known in this instant, and vice versa.”
  --Heisenberg, uncertainty paper, 1927

- Mathematically, if I measure the position of a particle with a precision $\Delta x$ and have a simultaneous measurement of the momentum with precision $\Delta p_x$, then the product of the two can never be less than $h/4\pi$
  - $\Delta x \cdot \Delta p_x > h/(4\pi)$
  - also, $\Delta x > h/(4\pi)$
Another Gedanken

The act of observing is going to disturb the object being observed.
What does it mean?

- A careless summary would be that “all things are uncertain”, but this is not really correct.
- “In the sharp formulation of the law of causality— if we know the present exactly, we can calculate the future—it is not the conclusion that is wrong but the premise.”
  --Heisenberg, in uncertainty principle paper, 1927

- Einstein could not accept this inherent uncertainty to the universe for the rest of his life.
And now... atomic structure

- In 1803, John Dalton proposed that matter was composed of round indivisible "atoms".
In his model all atoms of an element were identical.

They were kinda like indestructible little BBs.

His model allowed atoms to be rearranged but never to be created nor destroyed.

In addition, this meant more than 100 fundamental particles!

But the development of the periodic table suggested there was some sort of underlying structure.
Atoms are not fundamental

- Enter JJ Thomson
- In late 1890s, JJ did experiments using cathode ray tubes.
- By 1895, he had discovered electrons were coming from atoms.
Plum pudding model

- This led JJ to think of the atom as a positively charged mass sprinkled with negative electrons.
- These electrons seemed identical from different atoms.
- Thus electrons seemed to be a fundamental piece of matter.
By the time JJ had finished discovering the electron, experimental proof was found for Maxwell’s theory of electromagnetism.
Atoms are not stable

- Many researchers started to work with radioactive elements.
- A typical technique was to bombard some materials with radioactive particles.
- The New Zealander Ernest Rutherford was a leader in this type of research.
Types of radiation

- Alpha particles are helium nuclei (2 p, 2 n):

- Beta particles are speedy electrons:

- Gamma radiation is a stream of photons:
Rutherford had two graduate students, Marsden and Geiger.

It was decided that Geiger would gain some practice by conducting a series of experiments with gold and alpha particles.

The positively charged Alpha Particles were expected to go through the gold atoms and be slightly deflected.
Surprise, surprise, surprise

- On the screen, marks were only expected to appear in a limited region.
- Geiger was to explore the places where no results were anticipated.
- Marsden had to excitedly tell Rutherford that the new student had actually gotten results!
- Some were almost straight back!
• Rutherford would later compare it to firing a cannonball at a piece of tissue paper and having the ball bounce back!
• Rutherford quickly realized that a small, very dense and positively charged nucleus would account for the paths of the alpha particles.
• It took a lot of geometry and statistics to eventually convince other physicists and to show how big the nucleus was.
This led to the classic model of the atom—similar to the solar system. Distant electrons orbit a massive nucleus due to electrical forces of attraction. Rutherford’s model was very appealing but there were some “minor” problems that had to be solved.

What held the nucleus together to be so small? AND…

The orbiting electrons were giving off light, due to Conservation of Energy, they should eventually spiral into nucleus!
1. A powerful laser can emit in $1.16 \times 10^{-2}$ s an intense pulse of light having a total energy of 4130 J. If the wavelength of the emitted light is 640 nm, how many photons are emitted in this pulse? 

(h=$6.63 \times 10^{-34}$ J·s; c=$3 \times 10^8$ m/s)

a) 4130
b) 356
c) $1.33 \times 10^{22}$
d) $6.02 \times 10^{23}$
e) $4.98 \times 10^{20}$

2. Which of the following is true for the photoelectric effect?

a) the maximum energy of the ejected electrons is proportional to the intensity of the incoming photons
b) the maximum energy of the ejected electrons is proportional to the velocity of the photons
c) the maximum energy of the ejected electrons varies linearly with the frequency of the incoming photons
d) the maximum energy of the ejected electrons is proportional to the direction of the incoming photons