

## **Quantum Demystified**

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Quantum theory is a mystery to most people, including many physics teachers. Do we therefore need to bother secondary students with it?

It is essential to introduce quantum ideas at VCE level. Quantum has been the most successful advance in Physics of the twentieth century and has been the lynchpin behind devices like transistors, computers and electron microscopes as well as enlightening us about molecular chemistry and biology. The cosmology of supernovas, element creation and neutron stars uses quantum mechanics. Quantum computers are on the horizon now and closing. Thousands of predictions of quantum theory have been verified to seven figure accuracy and beyond. Shouldn't students know about all this?

### **Where to start**

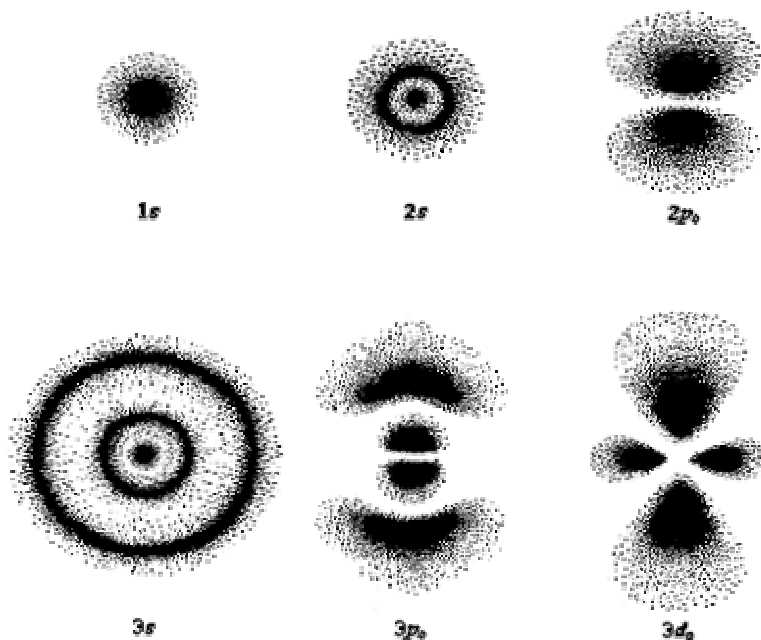
Unit 1 Physics begins with the study of light as *waves*. We can see that Schrodinger's wave analysis of the atom *works* (predicts the results of experiments). Heisenberg had a duplicate matrix analysis giving identical values for energy levels etc. His abstract mathematical treatment would be beyond most students. We need to focus on waves if we are to make quantum accessible to secondary students. Even though the wave function is said not to represent any measurable quantity, the postulate assumes there is *something* which has an amplitude and is vibrating with time at every point in space. Something is waving even if we don't know what it is exactly. Some have suggested it is a "guiding wave" which directs the electron into certain regions. It may be a wave, which is pulsing in hidden dimensions (superstring theory). The only firm conclusion is that the electron has to be treated as some kind of wave to make sense of the physical evidence. So students need a deep understanding of waves to begin to understand quantum concepts. In particular, they need to see standing waves in one dimension (springs) and two dimensions (vibrating plate) so that they can imagine standing waves in 3-D (electrons in atomic "orbitals").

Eventually, we want them to understand the emission spectra, which underpins most of our knowledge of the cosmos. We want students to connect the lines in the spectrogram to the arrows on the energy-level diagram (Unit 4) and thence to transitions between standing waves with different energies. Without the concept of standing waves the fixed lines on the energy-level graph have no explanation (just as the discrete musical notes of a hollow tube would have no meaning).

Properties like diffraction, refraction, superposition, reflection, partial-transition and standing waves can be demonstrated with springs and ripple tanks (or videos of such). The first two require the two dimensions of the ripple tank, but the last three can be easily demonstrated on a stretched spring. Students should obtain a strong feel for the way waves behave. From here they are well-placed to look at light and sound as wave

phenomena. Diffraction of light is simply demonstrated by getting students to look at the light in the room through a narrow gap between their fingers.

Refraction is easy with a Hodson light box. Particle and ray models for light can also be considered, to lead towards the essential quantum concept of wave/particle duality. Study of the behaviour and properties of light should show students the strength of the wave model (diffraction and refraction in particular).



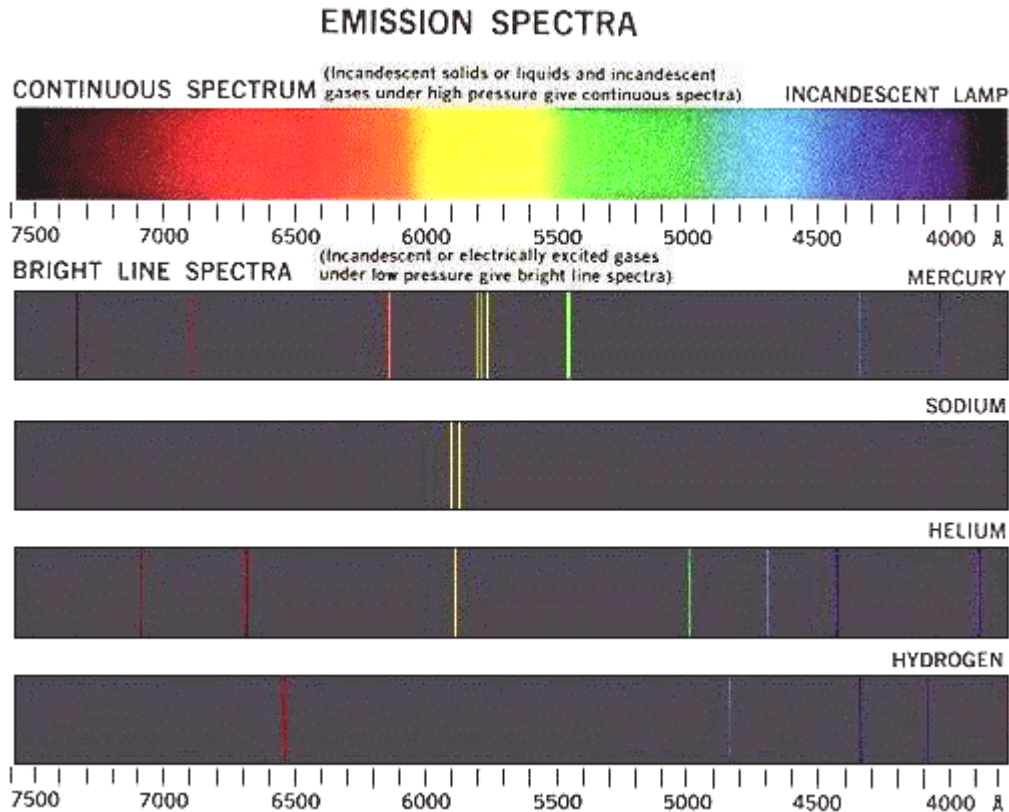
**Figure 6-12. Probability density plots of some hydrogen atomic orbitals. The density of the dots represents the probability of finding the electron in that region.**

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After studying waves in general and light as a wave phenomena, students should be introduced to models of the atom (Greek sphere, plum-pudding, solar-system planetary). This can be used as introduction to the Radioactivity and Nuclear Physics topic (Unit 1). Benjamin Franklin's experiments leading to discovery of the electron and the discovery of the nucleus and the empty space dominating the atom, by Rutherford, lead to the mystery of why the "orbiting" electrons don't radiate away their energy. (The electrons accelerating up and down a radio mast and radiating radio waves, or zooming around the synchrotron curves, illustrates this).

Finally we are in a position to introduce Schrodinger's wave model for the electrons in an atom. Year eleven students should be capable of making the connection between the standing waves on a spring "trapped" between the two ends and the idea of electron standing waves "trapped" in the space around the nucleus. The "harmonics" (standing waves with 2,3,4 etc nodes) visible on the spring can be related to the allowable energy levels of the electrons.

At this point it would be good to measure the main “yellow” spectral lines of a sodium lamp and to relate them to transitions between quantum (fixed quantity) energy levels in the sodium atom. Students could make their own simple spectrometer as done in the Switch on to Physics sessions.



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The introduction to quantum could be rounded off, by explaining how quantum explains the shape of molecules like water, and why carbon can form long chain molecules (in a spiral shape). The polar nature of H<sub>2</sub>O explains why it is a liquid and why it can dissolve so many substances. The complex shape of a gene or a protein determines its role in the scheme of life. Thus the whole of Chemistry and Biology is underpinned by quantum theory.

### Unit 3 Electronics and Photonics:

After a thorough grounding in the quantum model of electrons in standing waves and photons as wave-pulses caused by electronic transitions, students should be able to make sense of a very basic quantum explanation of the diode and the transistor. The idea of the base current adding energy to the collector /emitter current, allowing it to “vault” a quantum barrier is worth discussing in simple terms.

#### **Unit 4: Light and Matter:**

In year 12, after their knowledge of waves has been established, the quantum theory could be used in the explanation of :

- Young's double slit experiment (diffraction and interference patterns)

In particular, the mystery posed by Taylor's "one photon at a time" variation exposes the on-going difficulties in quantum theory.

- the photoelectric effect,

The energy-level diagram should now make more sense to students and the concept of the incoming energy being a fixed "quanta" determined by the photon wavelength

- crystallography via diffraction is a 3D extension of Young's double slit pattern.
- Another quantum example is the principle of the scanning electron microscope, which involves images formed by electron "waves" manipulated by magnetic "lenses" in an analogous way to optical lenses. Tunneling electron microscopes get electrons to leap an energy barrier because a small part of their wave function exists on the other side of the "wall". It's all pretty weird stuff to us as well, but students deserve to be given a glimpse of the strange quantum world, whilst also being shown that we are confidently predicting behaviour and using the theory in so many ways.

I hope quantum theory is a little less scary after this discussion, and I hope you can cope with knowing you are just a fuzzy wave (not just on Monday mornings).