Just in Time PD for Unit 4
Misconceptions in Quantum Physics

A collection of comments on misconceptions.

Common misconceptions in quantum physics include treating photons as literal billiard balls, assuming matter waves are physical fluid ripples, and misapplying momentum formulas.

Photon Momentum Misconceptions

- **"Light has momentum because it has mass":** People often think momentum requires mass (\(p = mv\)). Photons have zero rest mass, but they carry momentum derived from their energy via relativity (\(p = E/c\)).
- **"Photons are tiny physical bullets":** Visualizing a photon as a hard little sphere fails to explain interference or diffraction. A photon is a quantized excitation of an electromagnetic field; it spreads out like a wave and only behaves like a localized "particle" at the exact moment it exchanges energy or momentum with matter.
- **"Light pressure is just mechanical pushing":** Thinking of radiation pressure as a stream of pebbles bouncing off a surface ignores the underlying electrodynamics. The momentum transfer comes from the oscillating magnetic and electric fields of the wave interacting with charges in the material.

Matter Waves Misconceptions

- **"The de Broglie wave is a physical wave of substance":** Believing that an electron is literally smearing out into a physical cloud of dust or water-like wave is incorrect. The wave function (φ) represents a *probability amplitude* of where the particle will be detected, not a physical spreading of the object's body.
- **"Macroscopic objects don't have matter waves":** Assuming everyday objects like baseballs have ($p=0$) and no wavelength leads to confusion. They do have a de Broglie wavelength ($\lambda = h/p$), but it is so unfathomably small compared to the object's size that quantum interference effects can never be measured.
- **"Wave-particle duality means switching identities":** Imagining a particle magically morphs back and forth between a wave and a solid pebble over time is wrong. Quantum entities are distinct mathematical objects (field excitations) that always possess both characteristics simultaneously.

Four common misconceptions about quantum physics

1. A cat can be dead and alive
2. Simple analogies can explain entanglement
3. Nature is unreal and 'non-local'
4. Nobody understands quantum mechanics

Misconceptions in particle physics – THE PHYSICS DETECTIVE
Matter and Energy: A False Dichotomy – Of Particular Significance

More on Misconceptions

1. **Quantum physics is the physics of microscopic scale.**
2. This is true, but misleading. Quantum physics work **at all scales**, but we see quantum effects occur naturally when the action is low.
3. In fact, nanophysics and meta-materials, and quantum information all involve endeavours to extend quantum properties (coherence) to larger scales of space, time and energy.

4. **It is impossible to simultaneously know the position and the momentum of a system.**
   This is also misleading. It's **not a matter of knowledge**, it's a matter of **definition**. Heisenberg's inequalities do not mean that you don't have *access* to both informations simultaneously, they mean that those quantities are not *defined* simultaneously below a given uncertainty.
   Also, **I'd rather call them Heisenberg's inequalities rather than principle**. Calling them principle makes it sound like scientists created it as some sort of axiom, and that they would live in the fear that one day, Heisenberg's inequalities may be violated.
   In fact, it's kind of the other way around. Experiments hinted at a wave-like behaviour for low actions, and so the wavefunction formalism was established. **The principle is the fact that quantum systems are represented by an abstract wavefunction**. And the automatic consequence, by Fourier analysis, are the Heisenberg inequalities.

5. **Quantum mechanics and relativity are incompatible.**
   Again. This is misleading. Quantum mechanics and relativity are compatible, and one of the most important equations in physics is simultaneously quantum and relativistic : the **Klein Gordon equation**. It's the basis upon which quantum field theories, like QED and QCD, are built, and their predictive power is undisputed.
   The real issue is gravity for which the best model is General Relativity. But we would like to explain this interaction with a particle (graviton) and understand it with a quantum theory of gravity. In the same way the electron is an excitation of the electron-field, we would like the graviton to be an excitation in spacetime.