

# “Classical-ish”: Negotiating the boundary between classical and quantum particles

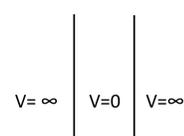
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## Developing quantum ontologies

- Developing a conceptual understanding of quantum mechanics includes developing ontologies for quantum entities (models for what kind of thing something is). [1-3]
- A quantum “particle” is different from both a classical particle and a classical wave, but we bring in classical intuitions with us when we learn quantum mechanics.
- What does it look like when students are negotiating the boundaries between classical and quantum ontologies while trying to make sense of a quantum system?

## Context: Particle in a box tutorial

- 5 physics undergrads (Al, Bob, Chad, Dan, Ed) taking 1<sup>st</sup>-semester quantum mechanics, and near the end of the semester
- Focus group setting (outside of class)
- Tutorial on the particle in a box (infinite square well)



## Data analysis

- Identifying ontologies through gesture analysis [4-5] and predicate analysis [6]
- Metacognitive utterances about the relationship between quantum and classical physics

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**References**

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**Question 3:**  
 Why isn’t the ground state  $n = 0$ ? That is, why isn’t it possible for the particle to have zero energy?

### It’s not classical, it’s quantum

Chad suggests that the question is trivial.

You can’t have a particle with no energy. That’s like saying I have a whole bushel of no apples.

No. What I think they’re saying is the difference, like, you could imagine, like in a classical sense, like a ball, in a well. It could just be sitting there. It could have no kinetic energy whatsoever.

Well, it has to. Velocity has to change.

Well, no, it doesn’t, because the potential’s constant.

Yeah, the potential’s just two walls...

...it’s not...

Right. So it’s not like harmonic, it’s not slowing down, it’s going at the same speed.

What they’re saying, I think, is like, why in a quantum realm, why it can’t—

Gesture represents classical particle

Gesture represents container

Al explains why it isn’t trivial: a classical particle **could** have zero energy. But a quantum particle is different.

### Hybrid classical/quantum ontology

Bob’s argument is based on the uncertainty principle: a particle can’t have both a definite position and a definite momentum. This is a property of a quantum particle.

If it has no energy, then it now has a definite position, and—

Definite momentum.

Yeah! It has a definite position and a definite momentum, which is impossible. ‘Cause you know its momentum is zero, and you know its position is right there, which is not possible.

At the same time, the idea that a particle at rest must have a definite position is based on a classical particle ontology.

Well, do you know where its position in the box is, if it has no momentum? Unless you know the initial state, you don’t know...

But you know it’s somewhere in a discrete position, and you know it’s, once you find it it’s gonna be right there.

But, ... if it’s infinite walls, then it can’t, like, go into it at all. So that disregards all quantumness. All of like the [gestures]

There’s no, like, leaking into the [gestures]

That, yeah. Leaking.

So it’s pretty much classical, isn’t it.

I’d say it’s pretty much classical.

Well—

Classical-ish. ‘Cause it has no reason to change speed.

But then Chad defends why a classical particle ontology is reasonable to use in this situation.

Gesture represent quantum wavefunction

### It’s not quantum, it’s classical

**Question 6:**  
 If you were to measure the speed of the particle at some point in time, what would you expect to measure? Why?

It’s particle in a box. Just bouncing off the walls back and forth?

Especially if we’re just saying it’s one-dimensional. Does it slow down at the edges?

Gesture represents classical particle

Well, it has to. Velocity has to change.

Well, no, it doesn’t, because the potential’s constant.

Yeah, the potential’s just two walls...

...it’s not...

Right. So it’s not like harmonic, it’s not slowing down, it’s going at the same speed.

Initially, the conversation is consistent with a classical particle ontology.

Is it going at the same speed then?

Velocity has to switch direction.

The velocity would change its direction.

Then Bob’s “meta” comment jolts the group out of this.

But, ... if it’s infinite walls, then it can’t, like, go into it at all. So that disregards all quantumness. All of like the [gestures]

There’s no, like, leaking into the [gestures]

That, yeah. Leaking.

So it’s pretty much classical, isn’t it.

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Gesture represent potential well

Gesture represent quantum wavefunction

## What do we see?

- Students are engaged in two different activities:
- Drawing on elements of various ontologies (including classical particles and quantum particles) to reason about the physical situation.
  - Stepping back to label their own reasoning as classical or quantum, and reflecting on which reasoning is appropriate in the context.

The green headings above show 3 different stances toward the relationship between classical and quantum ontologies in thinking about the particle in a box. The process of building intuitions about quantum entities can include drawing analogies to classical particles, as well as making explicit contrasts with classical particles.