Supercool Neutrons
(Ultracold Neutrons)

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Skywalk 2007

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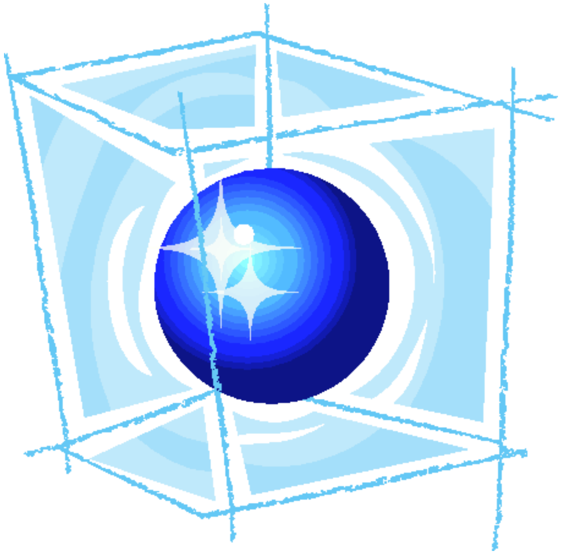
Ultracold Neutrons



- What are neutrons?
- Why are they important?
- How to make lots of neutrons.
- Interesting properties of ultracold neutrons (UCN)
- Super-cool experiments using ultracold neutrons
  - Neutrons, quantum physics, and gravity.
- The world's most intense source of ultracold neutrons

What are neutrons?

- Neutrons are a basic constituent of matter.
  - The atomic nucleus is made of neutrons and protons.

property	neutron	proton
electric charge	0	1e
mass	1 u	1 u
quark content	udd	uud

A neutron walks into a bar, sits down, and orders a drink.
Finishing, he asks, “How much?”
The bartender replies, “For you, no charge.”

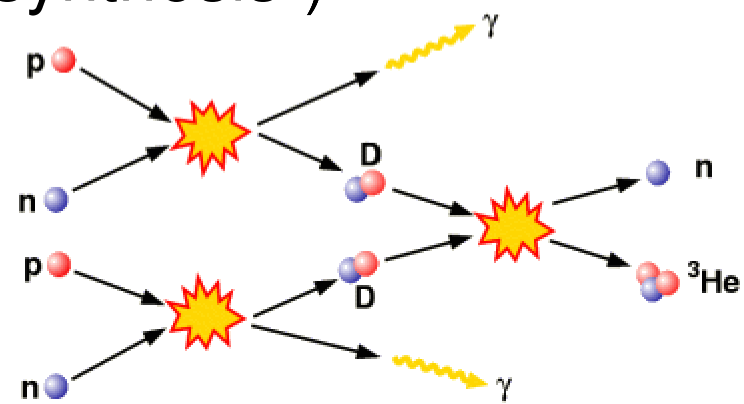
  - when freed from a nucleus, they decay

- Discovered by Chadwick in 1932 (Nobel Prize).

Why are neutrons important?

An historical overview.

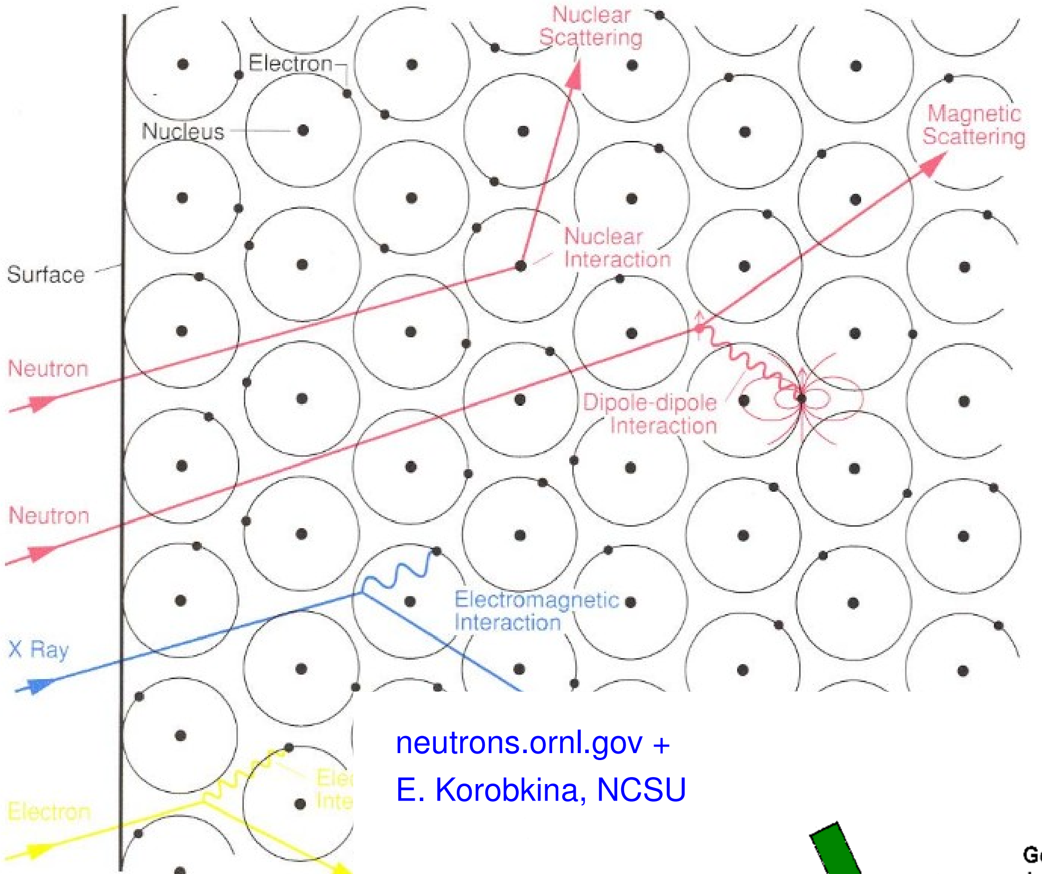
- Free neutrons were one of the first things present in the early universe. How fast they decayed determines how much of various lighter elements are currently present in today's universe. (“Big-Bang Nucleosynthesis”)
- Important for many reactions going on in our sun, and in nuclear reactors.



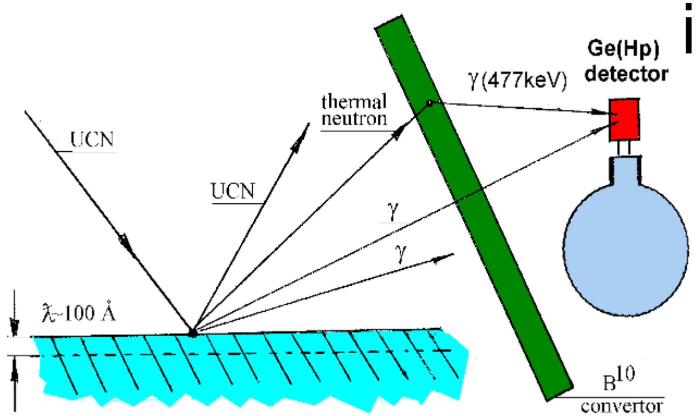
http://www.einstein-online.info

- Consequently, we're made of them.
- Nowadays, free neutrons are used to probe the structure of materials
- Fundamental Physics interest in studying neutrons

Technology and Neutrons



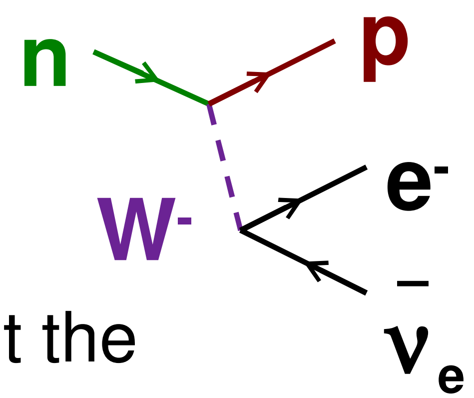
neutrons.ornl.gov +
E. Korobkina, NCSU



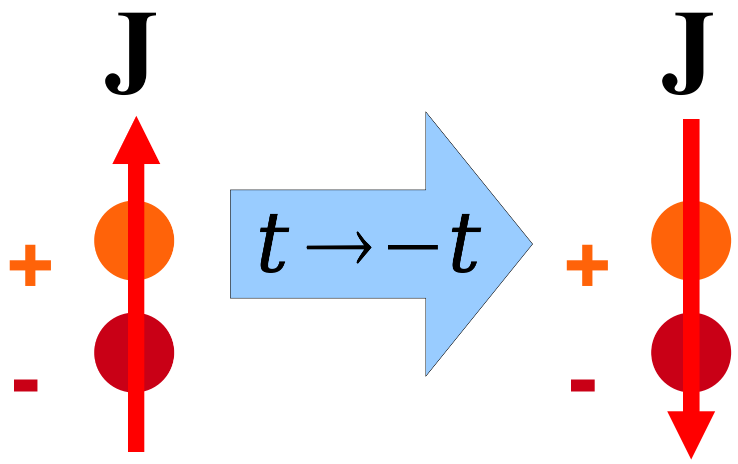
- Neutron scattering is a valuable tool to study the structure of materials.
- Because the neutrons have no charge, they interact mainly via the strong nuclear force with materials, giving a new window into the properties of materials.

Fundamental Physics and Neutrons

- Neutrons and their interactions are a hot topic in particle physics.
  - How fast do neutrons decay?
  - Details about how neutrons decay tell us about the weak nuclear force.



  - Does the neutron possess an electric dipole moment? The predominance of matter over antimatter in the universe.



  - Interactions of neutrons with gravity and are there extra dimensions? (more later)

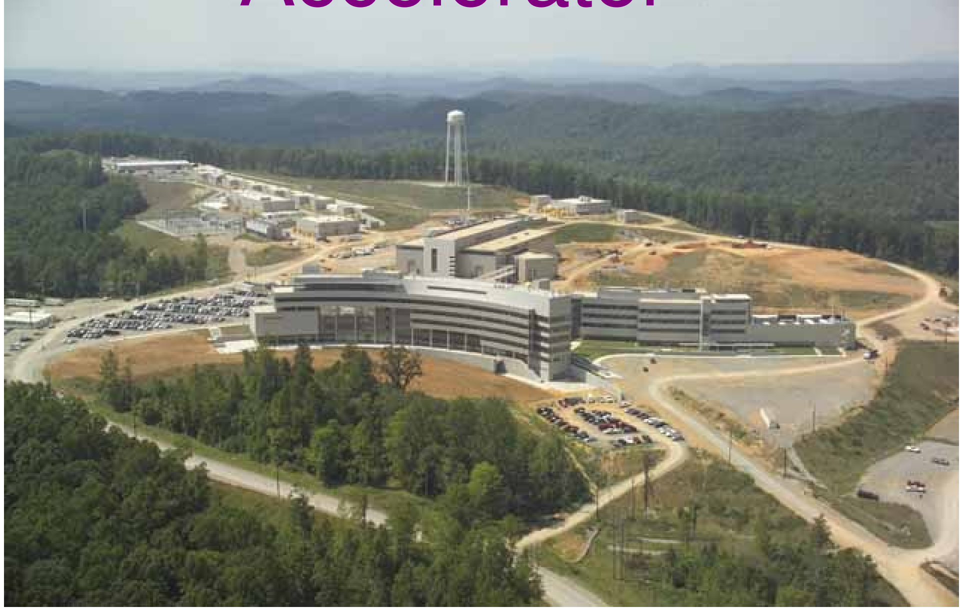
How to make lots of neutrons:

Liberate them from nuclei!

1) In a nuclear reactor (how the sun does it).

2) In an atom smasher (accelerator).

Accelerator

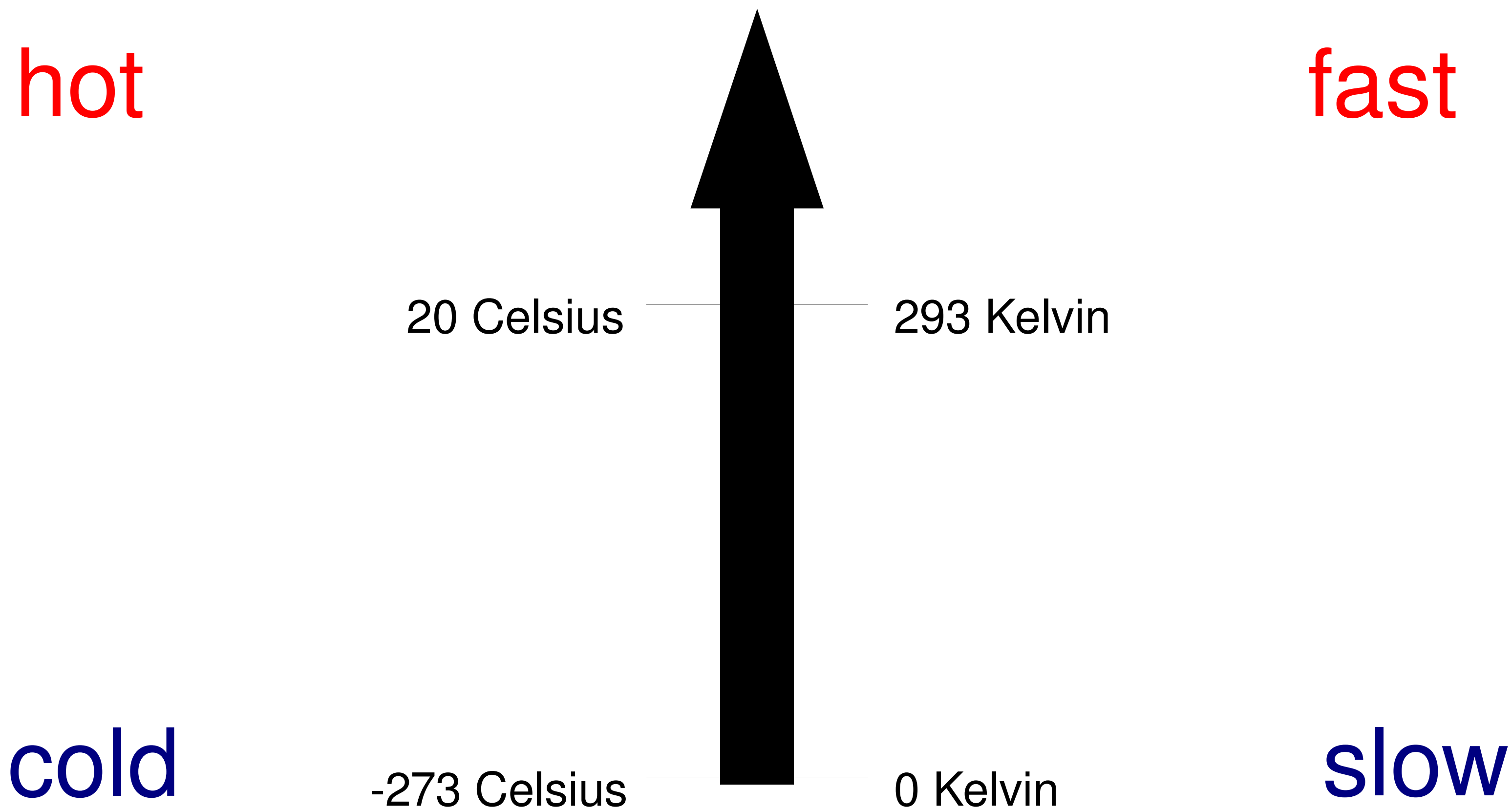


Spallation Neutron Source,
Oak Ridge, Tennessee, www.sns.gov

Reactor

Insititut Laue-Langevin,
Grenoble, France, www.ill.fr

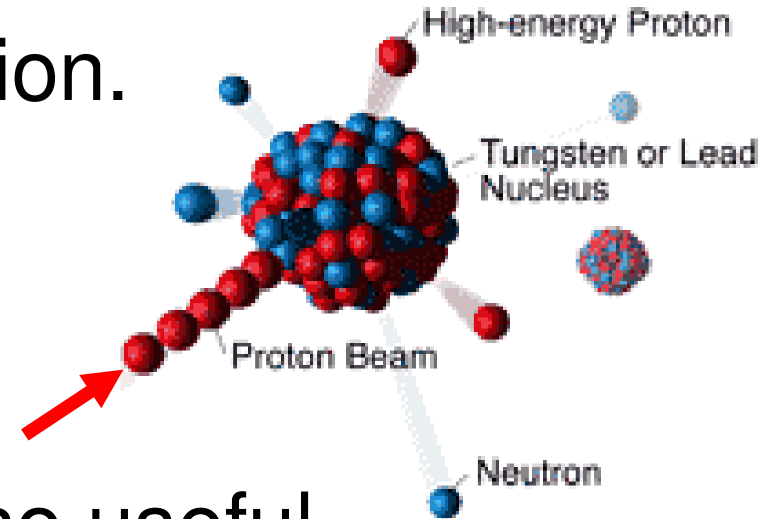
Temperature and Kinetic Energy



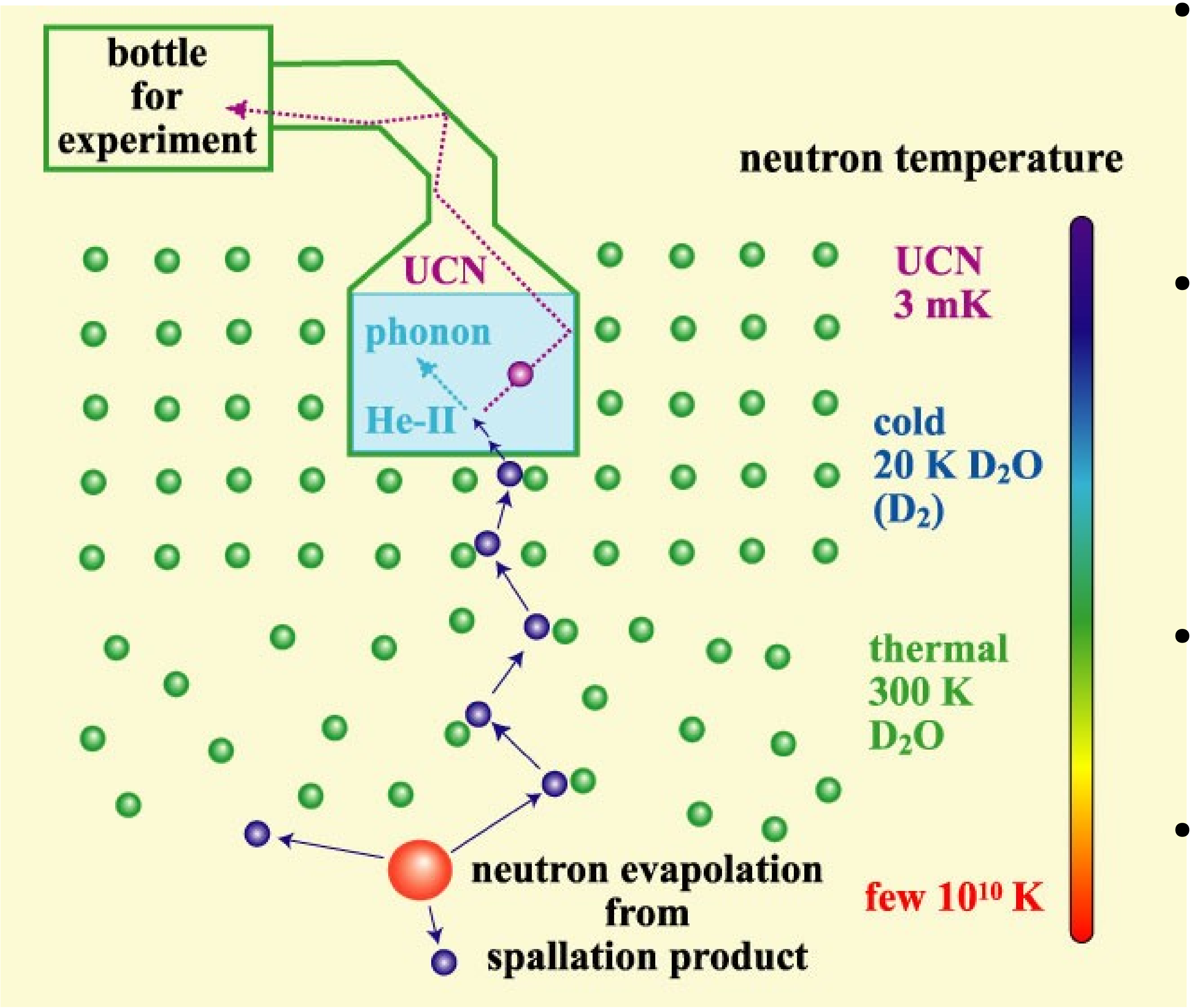
- At absolute zero (0 K) all motion stops!

How we make neutrons.

- Using proton-induced spallation.
- This makes very fast-moving neutrons (T = 1 billion K)
- Such “hot” neutrons are not so useful.
- We need to cool them down to make them useful (I'll show you why in a moment).



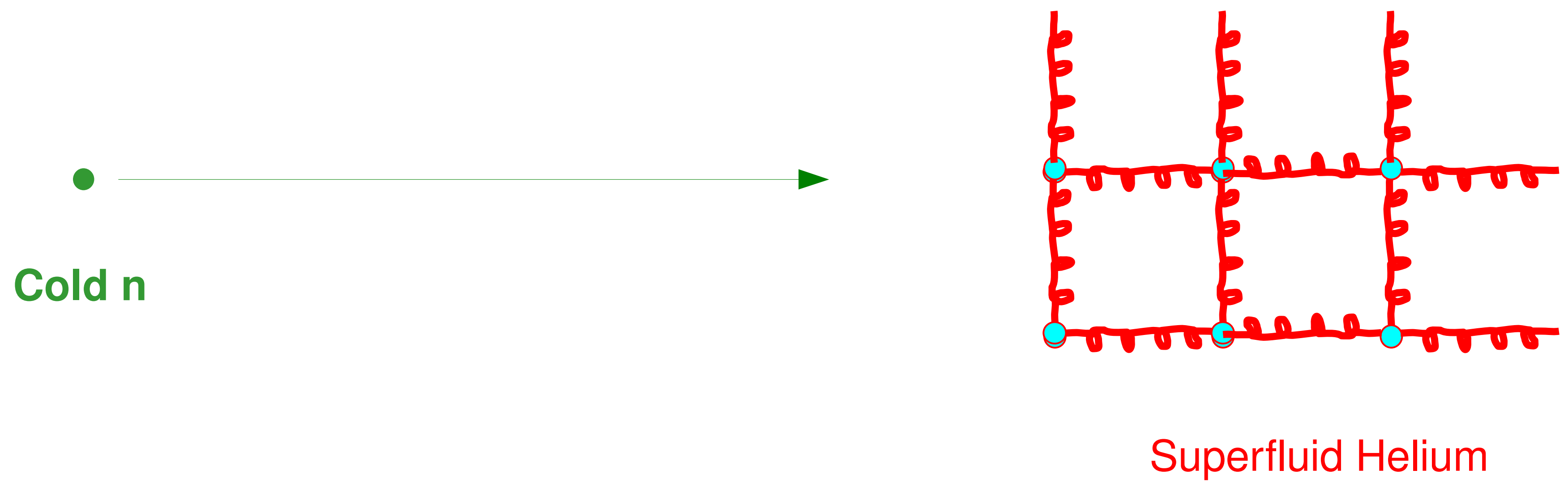
How we cool neutrons
Step One: Cold Neutrons



- Bring them into contact with a material at some temperature T.
- The neutrons bounce around for a while and eventually come into equilibrium with the material
- T = 20 K. (20 degrees above absolute zero.)
- But we desire ultracold neutrons

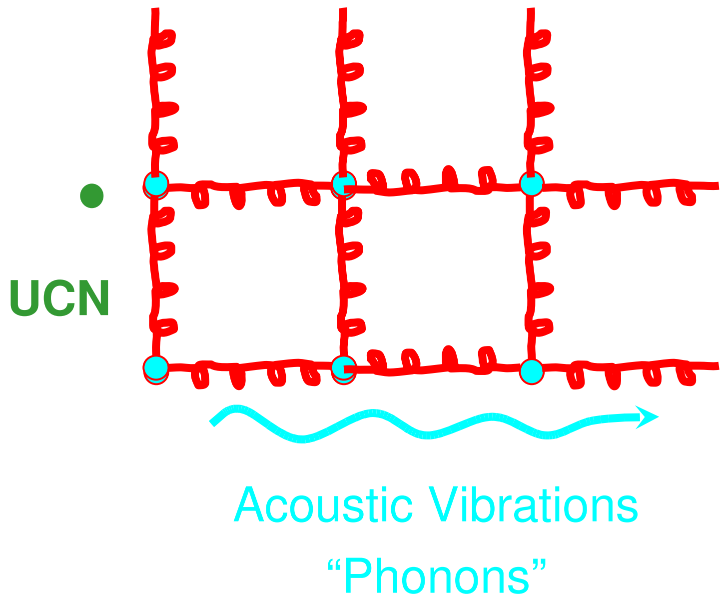
How we cool neutrons

Step Two: Ultracold Neutrons



- Scatter them off a material that doesn't absorb them (e.g. superfluid helium)

How we cool neutrons
Step Two: Ultracold Neutrons



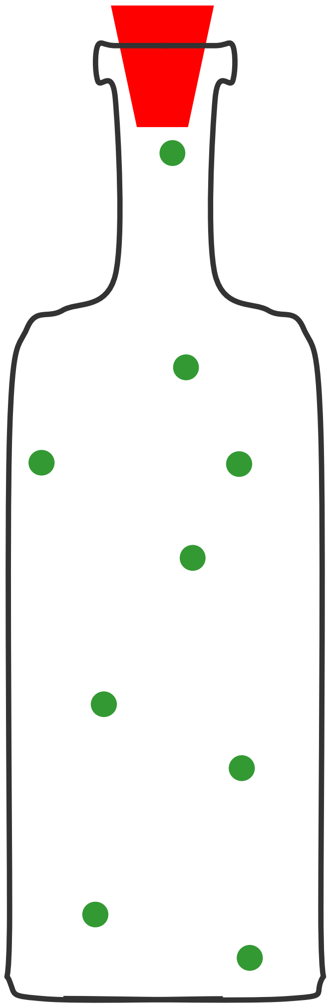
- Scatter them off a material that doesn't absorb them (e.g. superfluid helium) thus creating sound waves (“phonons”).

Properties of Ultracold Neutrons

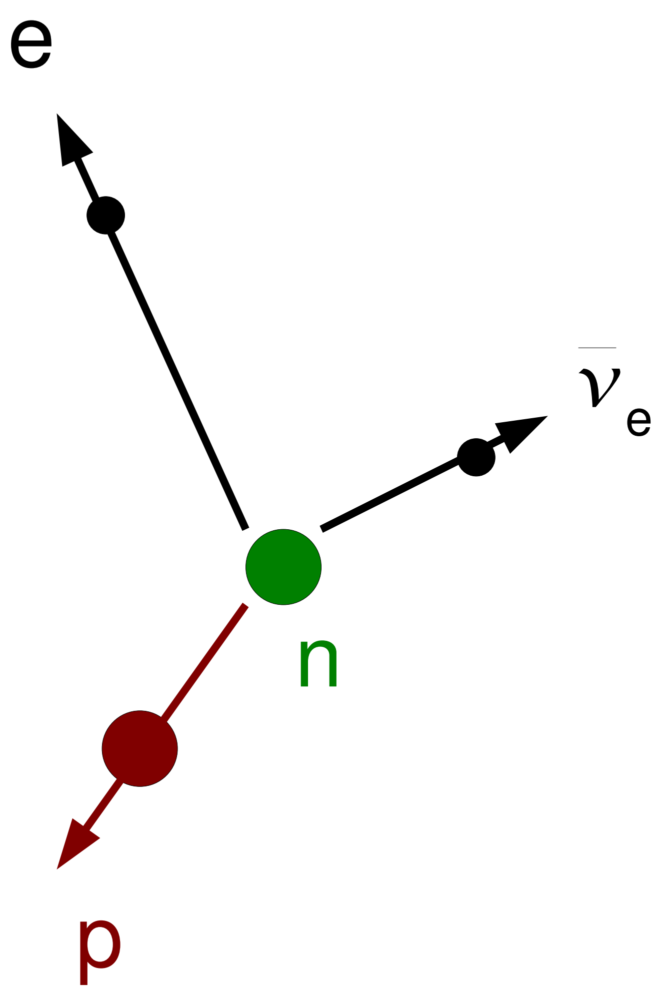
- Once the neutrons are ultracold they have some really very interesting properties.
  - Temperature < 0.004 K (degrees above absolute zero).
  - speed < 30 km/h
- Neutrons interact with the fundamental fields.
  - Strong nuclear force
  - Weak nuclear force
  - Magnetic force
  - Gravity

Strong Nuclear Force

- Ultracold neutrons are moving so absurdly slow that they undergo total reflection from surfaces.
- This arises because of the strong nuclear force (the neutrons bumping into atomic nuclei)
- Because of this, you can store them in a material bottle!



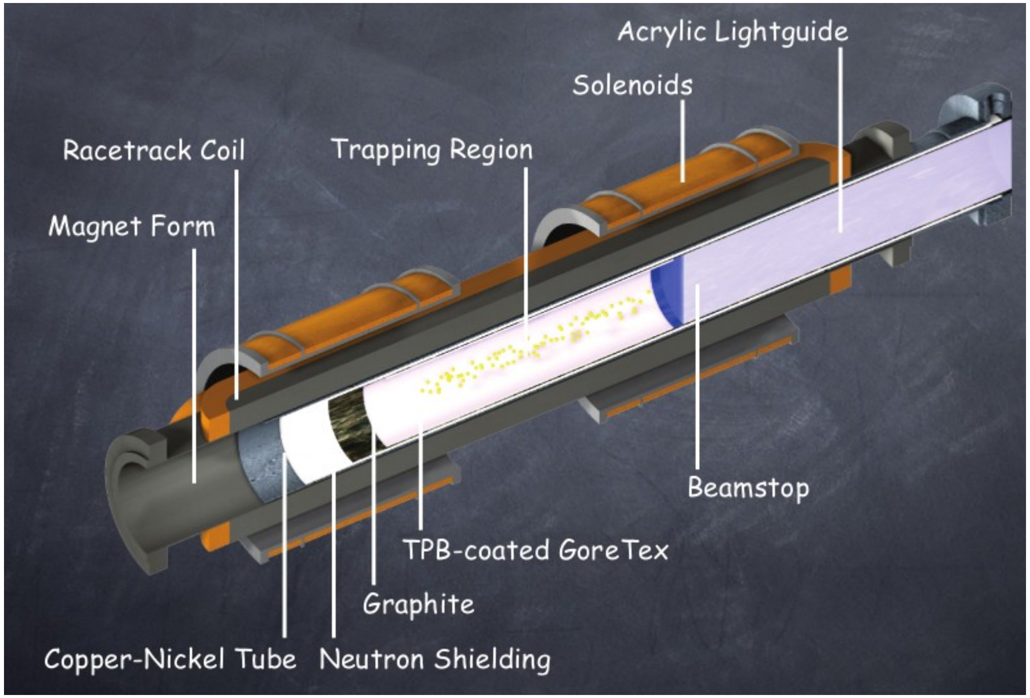
Weak Nuclear Force



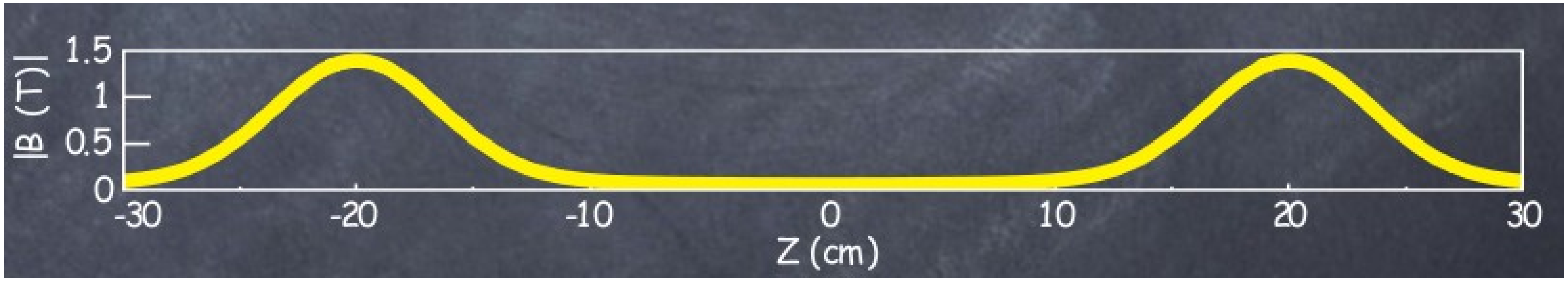
- Causes free neutrons to decay
- Neutrons live for about 15 minutes
- An interesting experiment:
  - Put ultracold neutrons in a bottle
  - Wait a while (about 15 minutes)
  - Open the bottle and see how many neutrons come out

Magnetism

- Neutrons have a "magnetic moment"
  - They behave like a little bar magnets.
- You can magnetically trap neutrons in a magnetic bottle!

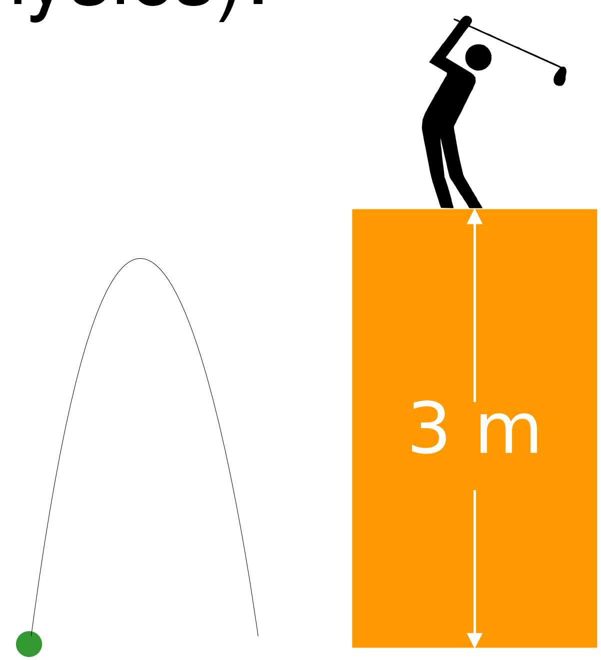


www.nist.gov



Gravity

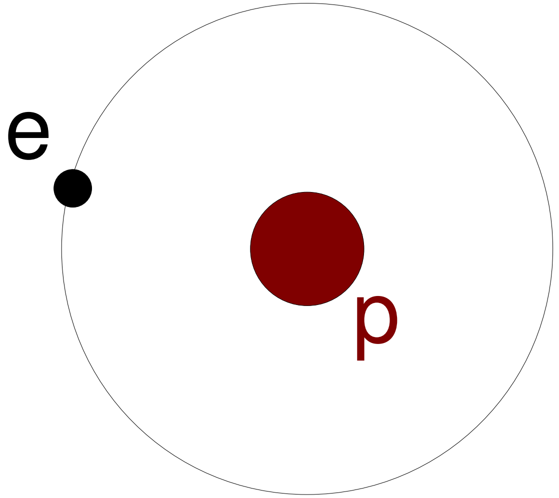
- Question: If I threw something straight up at an initial speed of 30 km/h, how high would it go?
- Answer (from high-school physics):
  - about 3 meters (10 feet).

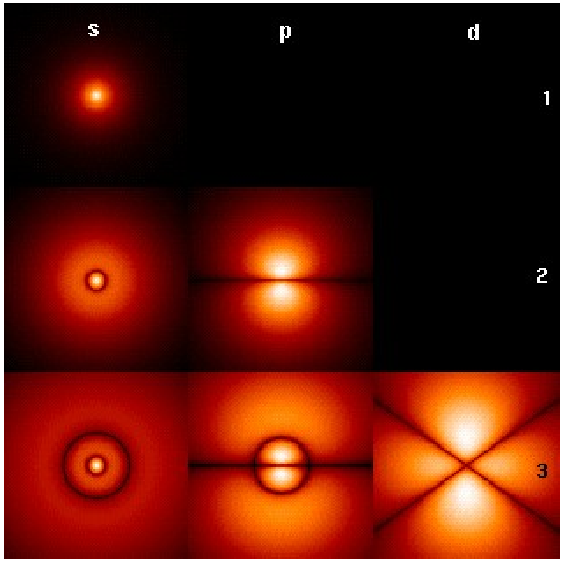


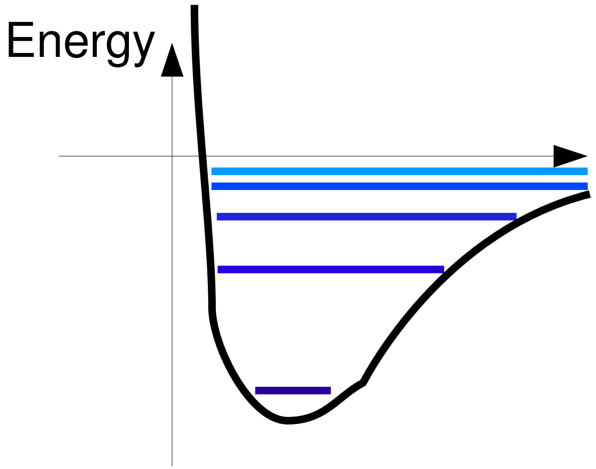
We'll revisit this in a moment.

Quantum Physics

- We think that everything in the universe is governed by the laws of quantum physics.
- However, quantum physics effects are only seen, generally, in really small things. (e.g. atoms ~ 0.1 nm = one-billionth of ten centimeters)
- One successful prediction of quantum mechanics is the “quantization” of energy levels for particles bound in potential wells. (e.g. H-atoms)

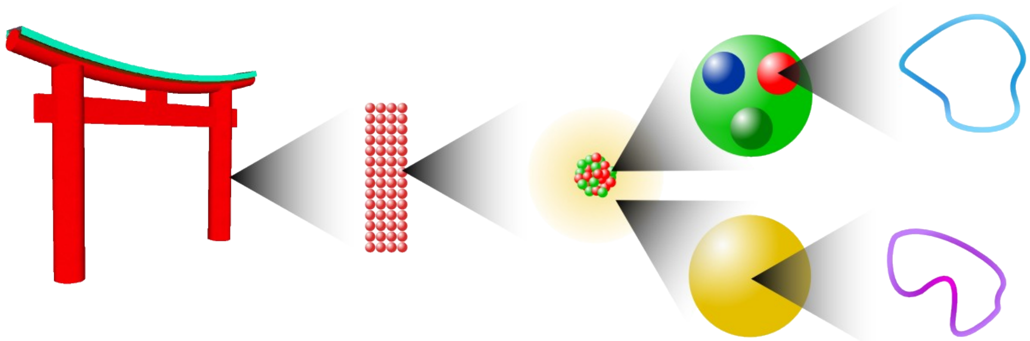






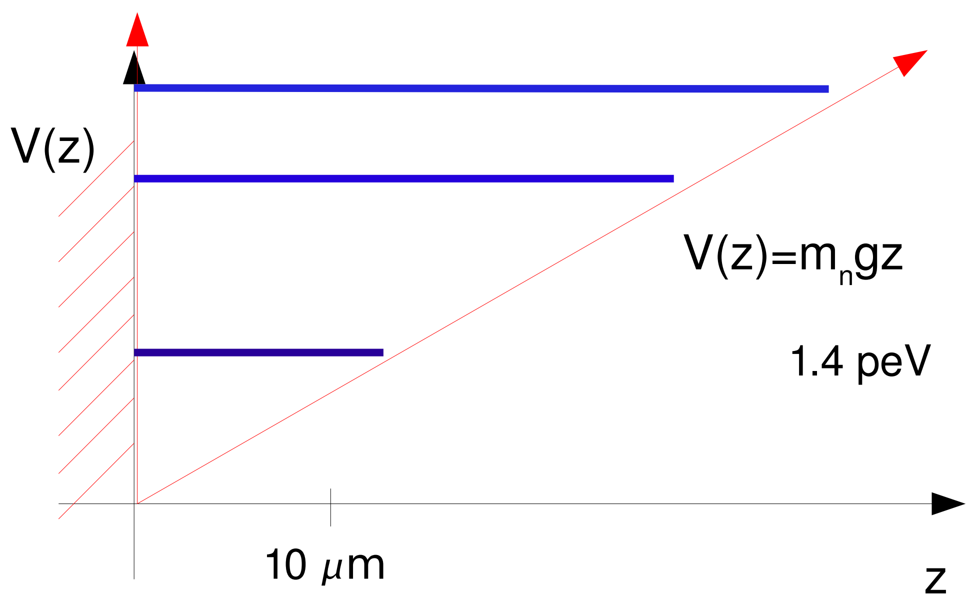
Quantum Physics and Gravity: They Don't Work Well Together

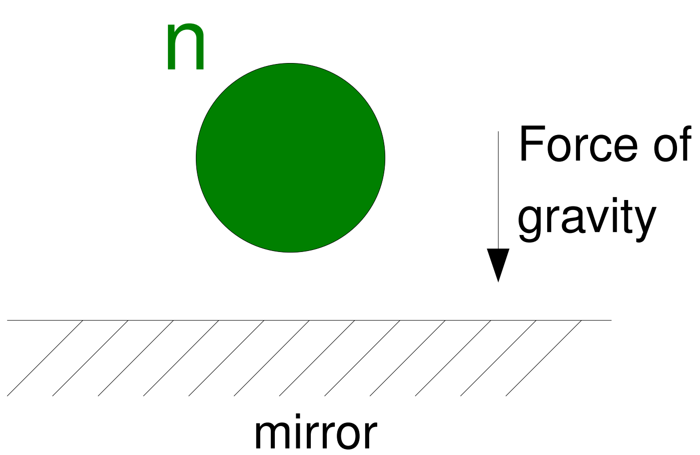
- So far, no one has figured out how to make gravity work with quantum physics.
- But people are trying:
  - string theory
    - might be the real quantum theory of gravity!
  - models of quantum behavior in black holes
    - J. Ziprick, G. Kunstatter, and R. Kobes, U. Winnipeg



Quantum Physics, Gravity, and Neutrons

- Ultracold neutrons can be confined in the Earth's gravity field.

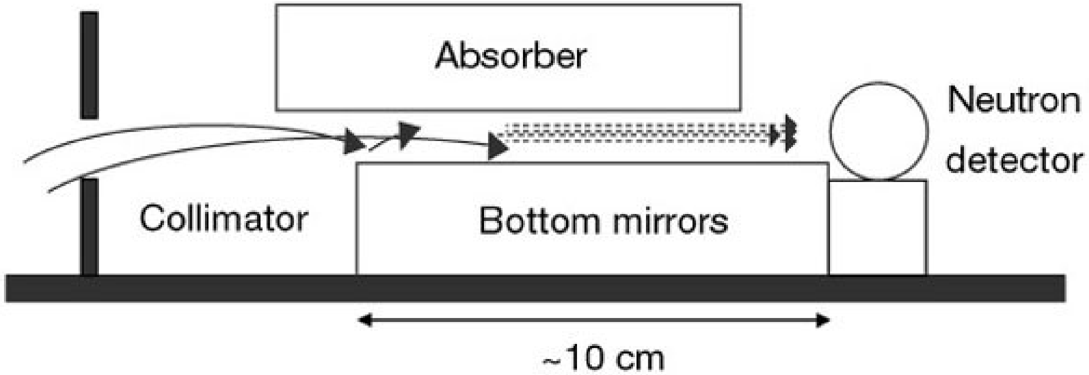


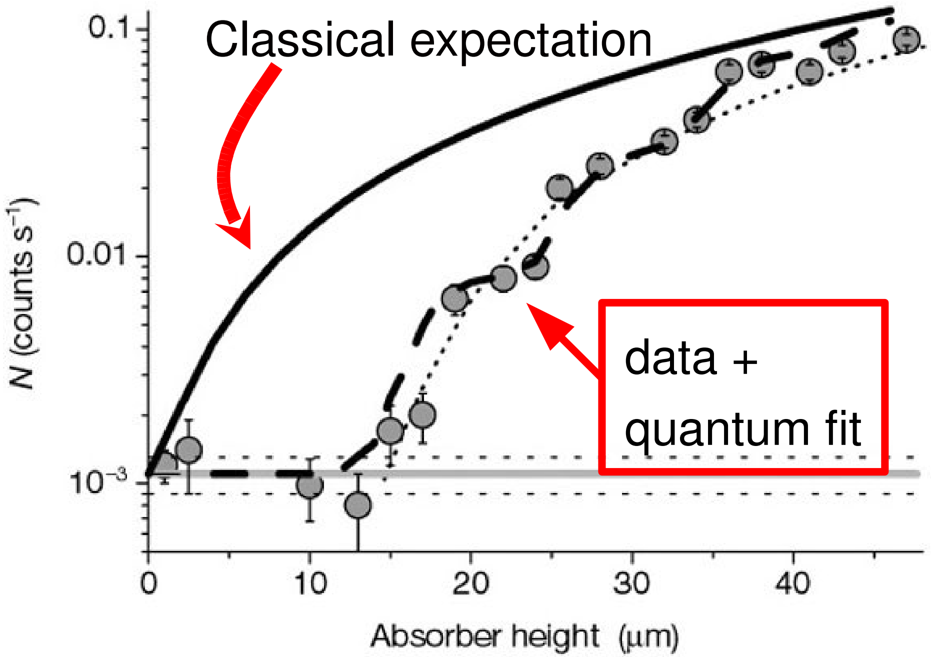


Quantum mechanically,
only particular energies are allowed

- Recently, the first observation of quantized energy-levels in the Earth's gravity field was made.

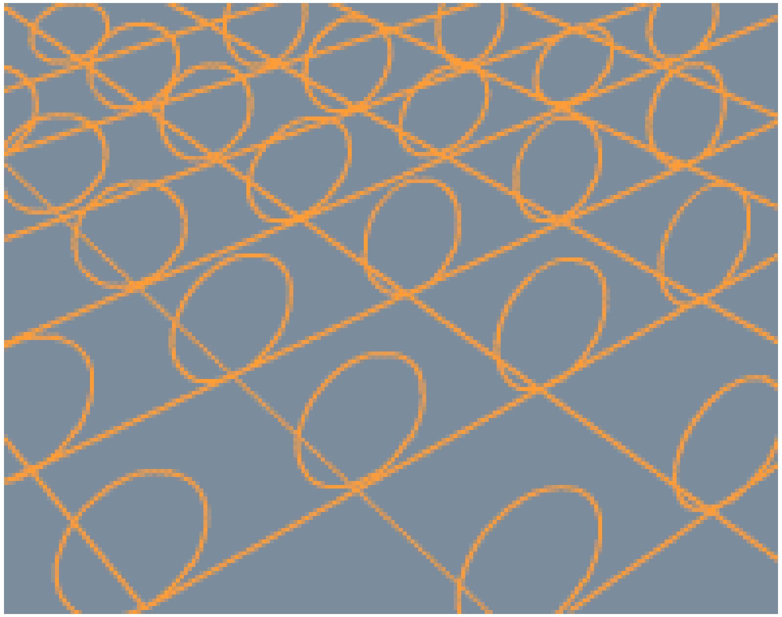
Experiment on Quantum Mechanics and Gravity





- Conducted in Grenoble, France.

Extra Dimensions?



- One “prediction” of string theory is extra dimensions.
- If they exist, where are they?
- Clever theorists have suggested that maybe they are “curled up” or “compactified”.
- These curled up dimensions would modify gravity at scales below the size of the curling.
- If gravity is modified at these scales, neutron gravity experiments should see it.

The Future of Ultracold Neutrons in Canada (I hope)

TRIUMF

CANADA'S NATIONAL LABORATORY FOR PARTICLE AND NUCLEAR PHYSICS

Owned and operated as a joint venture by a consortium of Canadian universities via a contribution through the National Research Council Canada

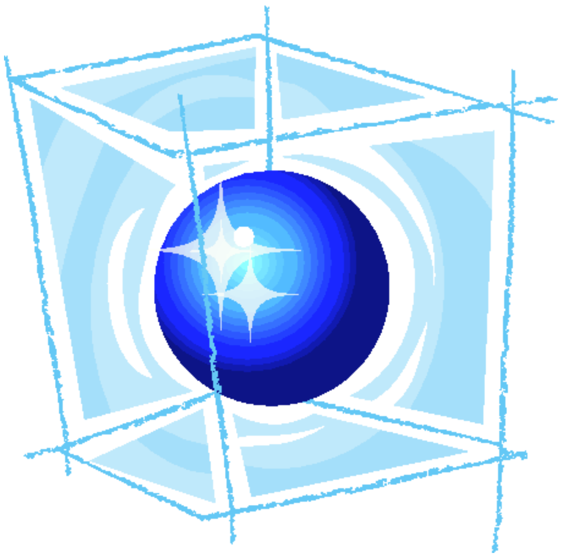
- I am proposing, along with others, to construct the world's most intense source of ultracold neutrons (at Canada's National Nuclear and Particle Physics Lab, TRIUMF, Vancouver).
- We hope to use these neutrons to provide:
  - new windows into materials science
  - the most precise test of quantum mechanics as applied to gravity and extra dimensions.

LABORATOIRE NATIONAL CANADIEN POUR LA RECHERCHE EN PHYSIQUE NUCLÉAIRE ET EN PHYSIQUE DES PARTICULES

Propriété d'un consortium d'universités canadiennes, géré en co-entreprise à partir d'une contribution administrée par le Conseil national de recherches Canada

Summary

- Ultracold neutrons are super cool.



- We can use them for a variety of purposes, for example to test quantum gravity.
- I hope to build the world's most intense source of ultracold neutrons, and locate it in Canada.

References

- My research group:
  - http://nuclear.uwinnipeg.ca
- My research at TRIUMF:
  - http://www.triumf.info/hosted/UCN
- The Particle Adventure:
  - http://www.particleadventure.org