Additional Notes for The Wind-Up Gods

The adventures of Newtonian Girl are about a woman who longs for the familiar and predictable world of Newtonian physics, but is instead faced with the strange and unintuitive trappings of quantum mechanics and relativity. These notes provide some insight into the physics behind the poems.

Newtonian Girl at Church. Newtonian or classical physics describes our normal macroscopic world. If you throw a ball, Newtonian mechanics can precisely calculate where that ball will land, how fast it's moving, what its momentum is, etc. Moreover, we are sure that the ball's mass stays constant and that this mass is a separate thing from the ball's energy. If, however, the ball were to move very fast, Newtonian physics would fail at describing the ball's behavior; as the ball approaches the speed of light, it becomes more massive and its shape appears to warp. If the ball had a watch wrapped around it, this watch will tick more slowly than the clocks where we are standing watching the ball fly past. This, along with Einstein's famous $E=mc^2$ (which uses the speed of light (c) to equate mass (m) and energy (E)), are some of the strange consequences of Special Relativity. This theory also plays a role in **Newtonian Girl Goes on a Date** and **Newtonian Girl at the Bris**. The latter makes note of a famous thought experiment called the Twin Paradox, in which one twin ventures out into space and returns only to discover that he's aged less than his earthbound brother.

Spacetime (which appears in **Newtonian Girl at Church** and in **Newtonian Girl Goes on a Date**) is a mathematical construct that helps physicists think about physical laws over all size-speed regimes. In Newtonian mechanics, time is a constant -- your watch and mine tick at the same rate, so spacetime is our normal three spatial dimensions. As we saw above, special relativity adds time as a fourth dimension because the rate at which time passes depends on how fast an object is traveling. General relativity adds an additional requirement: spacetime is curved by the presence of a mass, and this curving is a representation of gravity. In general relativity time also depends on the strength of gravitation fields which can slow its passage.

Newtonian physics also needs rescuing when objects get very small. Enter quantum mechanics, which was developed to describe the world of atoms and subatomic particles. Classic physics predicts that an atom's electrons should spiral in towards its nucleus, and that during their fall, it is possible to always know where these electrons are. Instead, quantum mechanics says that the electrons occupy only certain stable (quantized) energy levels, and the best we can hope for is a probability as to the electrons' location and energy state. Einstein was not comfortable with this probabilistic character of quantum mechanics, hence his famous statement, "I... am convinced that He does not throw dice." The last phrase in **Newtonian Girl at Church** alludes to this quote.

Another repercussion of quantum mechanics is the particle-wave duality, which is addressed by **Memoir of an Electron** and its epigraph.

The quantum mechanical inability to exactly peg the location and energy of a particle is the subject of **Newtonian Girl at the Laundromat.** Werner Heisenberg's "uncertainty principle" states that certain physical qualities such as position and momentum cannot both be known at the same time. Wolfgang Pauli was the author of "the exclusion principle" which says that particles cannot occupy the same quantum mechanic state at the same time. One quantum characteristic of a particle is its "spin". So if there are two electrons in one atomic energy level, one must be "spin up", while the other is "spin down".

The probabilistic nature of quantum mechanics is slightly mocked by **Either/Ors in Neat Cat Boxes**. It alludes to another famous thought experiment called Schrödinger's cat, which was introduced to show how bizarre one interpretation of quantum mechanics is when applied to every day objects. A luckless cat is put in a closed box with a vial of poison that can be uncorked by some random event. Until the box is opened, quantum mechanics considers the cat as being simultaneously alive and dead. A hyrax, by the way, is a real animal whose closest genetic relative is indeed the elephant. I was lucky to see a hyrax sitting on a wall surrounded by date trees near the Dead Sea.

are two physicists that helped elucidate some of the limits of knowledge

Pauli

Quantum mechanics

incorporates time with spatial dimensions. In

with our familiar three spatial dimensions. In classical mechanics time is thought of as a constant; if I am traveling on a train and you are watching from the ground, both of our watches will tick at the same rate. So spacetime can be reduced to the usual three directions. But in special relativity, time cannot be separated from the spatial dimensions because the rate at which times passes depends how fast an object is traveling relative to the speed of light (c).   General relativity adds an additional requirement: spacetime is curved by the presence of a mass, this curving is a representation of gravity. In general relativity time also depends on the strength of gravitation fields which can dilate it or slow its passage.

When things get much smaller, when we move from the macroscopic to the atomic scale, classical mechanics fails. For example, Newtonian physics incorrectly predicts that electrons should spiral in towards the nucleus of an atom, and that it's possible to say exactly where the electron is as it plummets. Instead quantum mechanics assigns discrete stable (quantized) energy levels for the electrons and can give only probabilities on the electron's location and energy state. QM also maintains that electrons and other objects that Classical physics thinks of as particles -- as well as light, which is thought of as a wave -- behave as both particles and waves. Newtonian or classical mechanics are a subset of relativity and quantum mechanics at low speeds and macroscopic sizes (although QM is needed to describe superconductors and superfluidity in the macroscopic world).

Schrodinger's cat

Schrödinger's cat is a thought experiment, often described as a paradox, devised by Austrian physicist Erwin Schrödinger in 1935. It illustrates what he saw as the problem of the Copenhagen interpretation of quantum mechanics being applied to everyday objects. The thought experiment presents a cat that might be alive or dead, depending on an earlier random event. In the course of developing this experiment, he coined the term **Verschränkung** (entanglement).

Quantum mechanics suggests that after a while the cat is *simultaneously* alive *and* dead. The superposition principle says that the way to describe the world is to assign such a complex number to every possible situation, and that the way to describe how things change is to treat these numbers mathematically as if they were probabilities. Because these numbers can be positive or negative, quantum mechanics allows the counterintuitive phenomenon that sometimes when there are more ways for a thing to happen, the chance that it happens goes down. An event with a negative amplitude can cancel with an event with a positive amplitude.

Broadly stated, a quantum superposition is the combination of all the possible states of a system (for example, the possible positions of a subatomic particle). The Copenhagen interpretation implies that the superposition only undergoes collapse into a definite state at the exact moment of quantum measurement.

According to Schrödinger, the Copenhagen interpretation implies that the cat remains both alive and dead until the box is opened.

Schrödinger did *not* wish to promote the idea of dead-and-alive cats as a serious possibility; quite the reverse: the thought experiment serves to illustrate the bizarreness of quantum mechanics and the mathematics necessary to describe quantum states.