Astronomy Bizarre — Wheeler
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(45005)

Review for Test #1
FORCES, QUANTUM THEORY, GRAVITY

Four forces of nature

- *Electromagnetic* – long range force; force is between charges. Opposite charges attract each other; like charges repel each other. A reasonably strong force.
- *Strong nuclear force* – short range force; acts to hold nucleus together. The strongest of all the forces at short range.
- *Weak nuclear force* – also short range force; associated with converting neutrons to protons and protons to neutrons. Intermediate in strength. Now understood to be an aspect of electroweak force.
- *Gravity* – long range force; force is between masses. Force is only attractive. The weakest of all the forces, by far on the atomic or nuclear scale.

James Clerk Maxwell – combined electricity and magnetism to create a theory of electromagnetism. Led to telegraph, telephone, radio, TV, electrical appliances. Electromagnetic radiation – light.

Steve Weinberg (and others) – combined electricity, magnetism and weak force into theory of electroweak force.

Grand Unified Theory – attempt to unite strong nuclear force with electroweak force.

Three Forces – strong, weak, and electromagnetic –are based on Quantum Theory

Gravity – separate theory

Isaac Newton – very successful prescription for force of gravity, $F = GM_1M_2/r^2$, but fails some sensitive tests and predicts gravity propagates at infinite speed.

Albert Einstein – Gravity is not a *force* in the sense of the other three quantum forces, but the effect of curved space. Gives results identical to Newton's equation for weak gravity, but very different concept. Einstein's theory of General Relativity has passed every observational, experimental test so far.

Fundamental problem – Einstein's theory has no aspects of quantum behavior.

Quantum Theory –

- <u>Exclusion principle</u> – particles like electrons, protons, neutrons, neutrinos, cannot occupy the same region of space if they have the same momentum (energy)
- <u>Uncertainty principle</u> – can only determine the probabilities of positions, speed, etc. Cannot determine any property exactly. Quantum uncertainty.
- <u>Quantum changes</u> – changes occur in quantum jumps.

Einstein's curved space theory of gravity applies to the World of the Large; planets, stars, galaxies, the Universe.

Quantum Theory applies to the World of the Small: molecules, atoms, particles.

Einstein's theory contains no quantum uncertainty. Quantum theory breaks down in highly curved space. Each theory contradicts the other conceptually, mathematically. Together they predict conditions where both are needed: origin of Big Bang, centers of black holes.

From conflict comes opportunity for grand new synthesis; Quantum Gravity, a Theory of Everything. Candidate: String Theory.

String Theory: all particles and forces between them arise from tiny, otherwise identical "strings" vibrating in different modes.

String Theory contains Einstein's theory as a mathematical subset, suggests 10 dimensions of space plus one of time, possibly parallel universes.

Application of Quantum Theory to Stars.

Stellar balancing act – dynamic equilibrium. A star spends most of its lifetime at a relatively constant size, temperature, luminosity, etc. while it fuses some fraction of its hydrogen into helium. During this time there is a balance between the forces inward and the forces outward.

Force inward due to gravity. Without the pressure forces acting outwards the star would collapse.

Force outward—pressure

Thermal pressure. For most of the lifetime of the star this is the dominant source of outward pressure.

With thermal pressure a star can *regulate* its temperature. If too much energy is temporarily lost, the star contracts and heats, increasing nuclear input. If too much energy is temporarily gained, the star expands and cools, and nuclear input declines.

Quantum pressure. Electrons cannot occupy the same region of space if they have the same energy. As matter is squeezed down, electrons develop more quantum energy that depends only on the density and is independent of the temperature. The electrons' resistance to being squeezed any closer together provides a quantum pressure independent of temperature.

With quantum pressure a star cannot regulate its temperature. If such a star (or stellar core) loses energy, it cools since pressure does not depend on the temperature, so there is no loss of pressure and the star does not contract and heat. If the star gains energy, it heats up, more nuclear reactions, more heat, → explosion!