MODERN PHYSICS IN A NUTSHELL

Modern Physics -- physics that applies to systems that are very small (size of an atom), very fast (approaching the speed of light), or in very strong gravitational fields (near a black hole).

Two Pillars of Modern Physics

1. Quantum Theory (for small systems)

2. Relativity
   Special Relativity (for fast systems)
   General Relativity (for strong gravitational fields)

Quantum Theory

Energy is not infinitely divisible.

Energy comes in discrete chunks called "quanta" ("quanta" is the plural of "quantum")

Each type of energy has a special name for its quanta.

photon -- the quantum of a electromagnetic energy
graviton – the quantum of gravitational energy.
phonon – the quantum of vibrations in a solid substance
etc.

Any particular quanta has a particular frequency.

Example: the photons emitted by a red laser pointer has a frequency of 450×10^{12} cycles per second

Example: the photons emitted by radio station Power106 has a frequency of 1.06×10^{6} cycles per second

The energy of a quantum is proportional to its frequency

$$E = hv$$

$E = energy;\quad h = Planck's\ constant;\quad v = frequency$

Value of Planck's constant *h*

$h = 4.14 \times 10^{-15}$ eV-sec
$h = 6.63 \times 10^{-34}$ Joule-sec

Electrons in an atom can only have certain values of energy.

Example:
An electron in a hydrogen atom can only have values for its energy that are part of this series: -13.6 eV, -3.4 eV, -1.5 eV, **...**

[i.e. energies given by $E = -13.6eV/n^2$, *where n = (1, 2, 3, 4,...)*]

So an electron in a hydrogen atom *cannot* have an energy of -13.9 eV or -2.7 ev.

[Energies of particles bound in atoms are negative. Those of particles that are free are positive.]

Quanta have wavelengths that are inversely proportional to their frequency.

Wavelength = (speed of light)/frequency

$$\lambda = \frac{c}{\nu}$$

λ = wavelength
c = speed of light = 3 x 10^8 m/s
ν = frequency

Special Relativity

Moving clocks appear to slow down (except to someone moving with the clock).

$$t = \gamma t_0 \qquad \gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

t_0= time between ticks of stationary clock
t = time between ticks of moving clock
v= speed of moving clock
c= speed of light
Note that $\gamma \geq 1$

Moving rulers appear to shorten (except for someone moving with the rule)

$$l = \frac{l_0}{\gamma}$$

l_0 = length of stationary ruler
l = length of moving ruler
γ is the same as above

Moving masses appear to increase (except for someone moving with the mass)

$$m = m_0 \gamma$$

m_0 = mass of stationary object
m = mass of moving object
γ is the same as above

The mass of a particle can be converted into energy.

$$E = mc^2$$

E = energy
m = mass
c = speed of light

General Relativity

Describes gravity as the result of the bending of space and time (spacetime):

Mass and energy bend spacetime.

The bending of spacetime directs the motion of particles.

["Mass tells spacetime how to bend; spacetime tells mass how to move."]

Accurately describes very strong gravitational fields (where Newton's theory breaks down).

Predicted that

Gravity bends the path of light (confirmed)

Gravity lowers the frequency of photon that climb out of a gravity well. (confirmed)

Black holes (objects with gravity so intense that light cannot escape) exist. (confirmed)

Wormholes (interstellar shortcuts) might be possible. (unconfirmed)

The universe is not static. (confirmed)