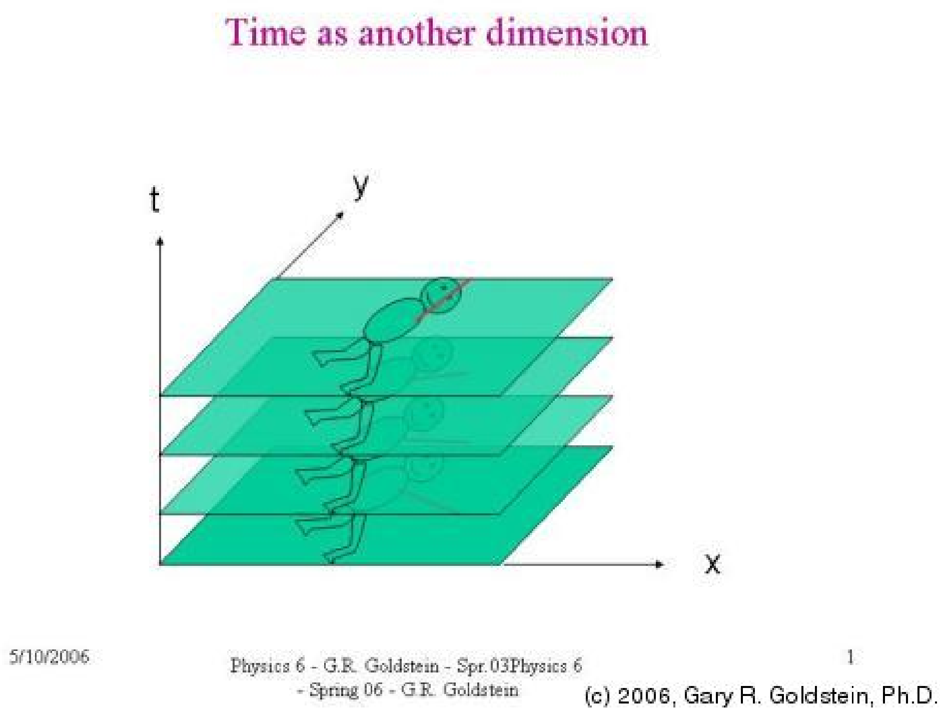
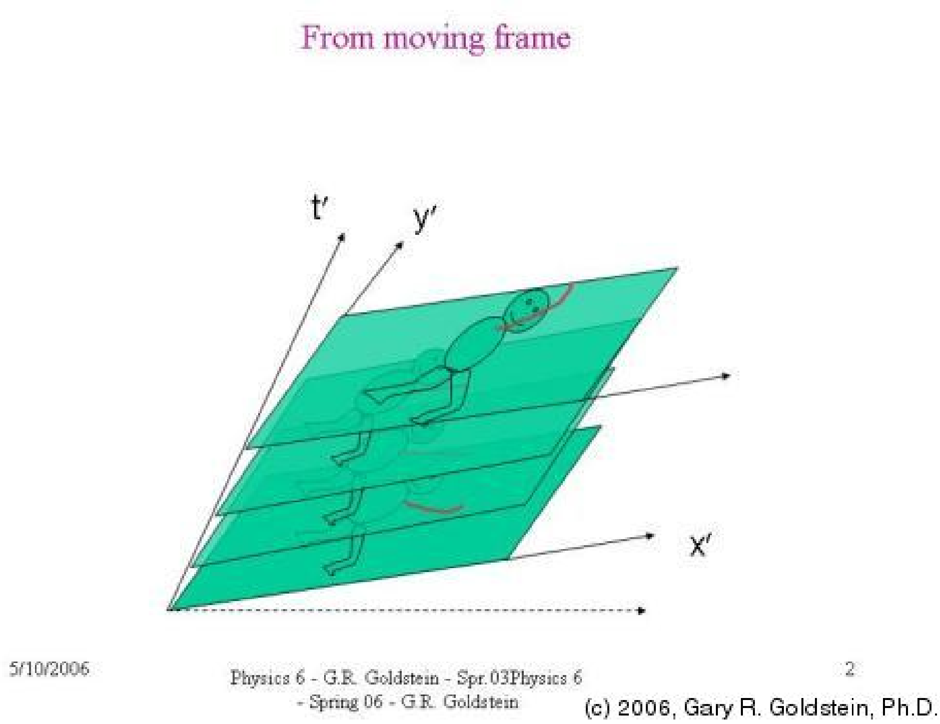
1. Time as another dimension

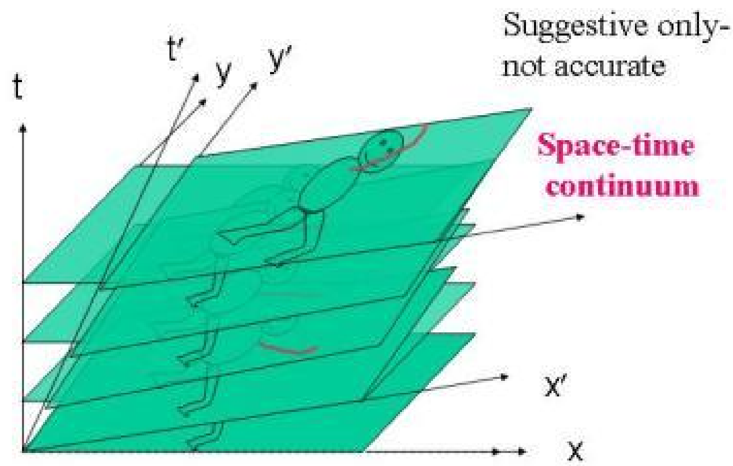


2. From moving frame



3. Both frames superimposed

Both frames superimposed



5/10/2006 Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein 3

4. Relativistic Energy conservation

Relativistic Energy conservation

So Einstein: "if the energy changes by L, the mass changes in the same sense by L/c^2."

In general, for any kind of energy release or change E,

$$m = E/c^2$$

$$\text{or } \mathbf{E = mc^2}$$

"**The mass of a body is a measure of its energy content**."

"It is not excluded that it will prove possible to test this theory using bodies whose energy content is variable to a high degree (e.g. radium salts)." As M. Curie had recently discovered, Radium emits EM radiation spontaneously.

5/10/2006 Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein 4

5. Energy for object at rest

Energy for object at rest

For object at rest (or in rest frame of object) $u = 0$

$$E = m_0c^2$$

For moving objects,

and E is Conserved

$$E = \frac{m_0c^2}{\sqrt{1 - \frac{u^2}{c^2}}}$$

What about "mass conservation"?

Total mass input can differ from Total mass output.

What kind of energy is this "Rest Energy"?

Many forms of energy-heat, EM, sound, gravitational

Energy is Conserved

5/10/2006 Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein 5

6. Relativistic Energy

Relativistic Energy

Rest Energy $E = m_0c^2$ for $c = 3.00 \times 10^8$ m/s

Scale: If $m_0 = 1$ Kg,

$E = 1 \text{ Kg} \times (3.00 \times 10^8)^2 = 9.0 \times 10^{16}$ Joule

$\approx 2 \times 10^4$ kiloTons of TNT (huge!)

or released over 1 yr --> $9 \times 10^{16}\text{J} / 3 \times 10^7\text{sec} = 3$ GW (3 Nplants)

How to convert from rest energy to other forms?

Note that $E = m_0c^2/\sqrt{(1-u^2/c^2)}$ for "slow" motion

becomes (u/c << 1, binomial expansion)

$1/\sqrt{(1-u^2/c^2)} \approx 1 + 1/2\, u^2/c^2$

So $E \approx m_0c^2 + 1/2\, m_0u^2$ for small u/c

Rest energy (m_0c^2) — Classical Kinetic Energy ($1/2\, m_0u^2$)

5/10/2006 Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein 6

7. Energy units

Energy units

- Standard MKS units:
  - speed~distance÷time m/sec
  - acceleration~speed ÷time (m/sec)/sec~m/sec^2
  - force~mass × acceleration 1Kg × m/sec^2 =1N (Newton)
  - energy~force ×distance 1N × 1m = 1 Joule
- Other energy units:
  - heat: 1 calorie=4.2 J (1gm H_2O 1°C) (1 Food Calorie=1000 calories)
  - nuclear and particle physics: 1 electron Volt = kinetic energy of electron accelerated by 1 Volt = 1.6x10^{-19}J
  - nuclear weapons: 1 Kiloton TNT=4.2x10^{12}J
- Power ~energy÷time 1 J/s = 1 Watt (kilowatts, megawatts)
  - 1 KWh=10^{3}W×1hr=10^3×3600 J =3.6x10^{6}J (100 watt bulb ×10hr)

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8. Energy units-2

Energy units-2

- Energy has many forms and many units
  - Mechanical work (Work=F•d), gravitational potential, kinetic, heat, EM, electrical potential, chemical, nuclear, …(see Feynman Chapter 4)
- Amount of work required to lift 1 Kg a distance of about 10 cm (0.1 m) is (using g =9.8 m/s^2 ≈ 10 m/s^2)

  ≈ 1 **Joule** of energy (MKS) = 10^7 **erg** ≈ 0.7 **ft-lb**

  ≈ 9x10^{-4}**BTU** ≈ 6x10^{18} **eV** ≈ 3x10^{-7} **KWh**

  ≈ 0.2 **cal** (1/1000 **food Cal**) different units for different sizes of phenomena

  - 1 Kg (mass) *weighs* 2.2 **lbs** (force=m•g)

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9. Nuclei and isotopes

Nuclei and isotopes

- Read Feynman Chapters 1 (& part of 2) to review molecular-atomic theory (+ Chap.4 Energy)
- Matter $\supset$ molecules $\supset$ atoms $\supset$ electrons & nuclei $\supset$ protons & neutrons
- Ordinary Hydrogen: $1e^- + 1p^+$ Z=1
- deuteron nucleus: $1p^+ + 1n^0$ Z=1 and A=2 $_1^2H$
- Z = atomic number
  A = atomic weight or mass number
- Single Z & different A's **isotopes**
  - See http://ie.lbl.gov/education/isotopes.htm
- U(235), U(238) both Z=92
- $_{92}^{235}U$ and $_{92}^{238}U$ U235 is 0.7%

5/10/2006 Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein 9

10. Periodic Table

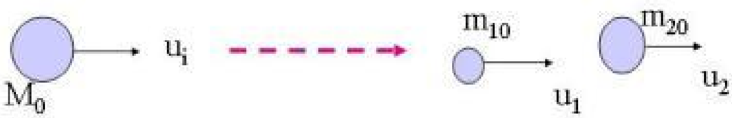
Periodic Table

See http://www.chemicalelements.com to fill in atomic numbers, electron configurations, etc.

5/10/2006 Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein 10

11. Nuclear fission and fusion

Nuclear fission and fusion



- $E_i = K_i + M_0c^2 = E_f$ (i=initial, f=final, K is Kinetic Energy)
- $E_f = E_1 + E_2 = K_1 + K_2 + m_{10}c^2 + m_{20}c^2$ where $K_f = K_1 + K_2$
- So $K_i - K_f = m_{10}c^2 + m_{20}c^2 - M_0c^2 = (\Delta m_0)c^2$
- (Δm_0) is the mass increase of final nuclei
- If negative then M_0 has a "mass surplus" $\Rightarrow$ produce extra E
  - i.e. part of initial rest energy becomes kinetic (or other) energy - FISSION
- If positive then M_0 has a "mass defect" $\Rightarrow$ **reverse** reaction favored
  - $(m_1+m_2 \rightarrow M_0)$ will produce extra kinetic (or other) energy- FUSION

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12. Fusion

Fusion

- Example - deuteron = d = ${}^2_1H$ ~ p and n
  - $m_dc^2 < m_pc^2 + m_nc^2$ by 2.2 MeV (binding energy)
  - So n + p -> d + 2.2 MeV (extra KE or radiation)
- Solar energy
  - d + t -> He + n + 17.6 MeV extra energy
  - or ${}^2_1H + {}^3_1H \rightarrow {}^4_2He + {}^1_0n$ + Energy
  - need cycle at very high temperature to overcome Coulomb repulsion between plus charges
  - Enhance energy by many $N_{avogadro}$ for sun or star
- H bomb
- Fusion Power Plants?

5/10/2006 Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein 12