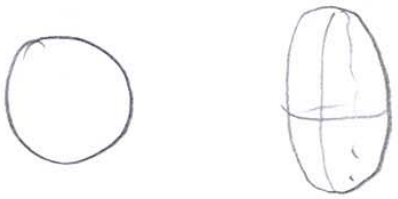
(11) Meaning of field eq'n:



volume preserving to lowest order in vacuum.

fractional change in matter $\ddot{V}/V = -4\pi G(\rho + 3p)$

$\nabla^2\phi = 4\pi G \rho_m$

$\frac{1}{T^2} \quad \frac{1}{c^2}$

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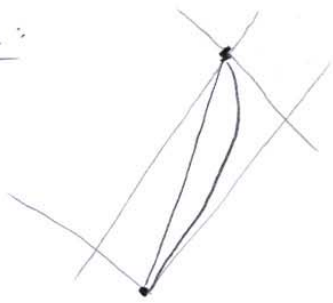
(12) examples ... gravity waves, cosmology, etc etc.

(a) Particle or light ray motion?

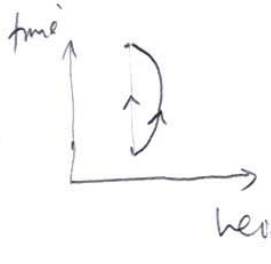
Flat spacetime:



Straight path longest time.

Curved spacetime: geodesic (longest time between 'nearby' points)

example:



variational principle: $\delta \int \sqrt{-ds^2} = 0$

(12 ctd.)

$$\text{or} \quad \delta \int \underbrace{\left(g^{(x)}_{\alpha\beta} \frac{dx^\alpha}{d\lambda} \frac{dx^\beta}{d\lambda} \right)}_{\text{"Lagrangian"}} d\lambda = 0$$

given $g_{\alpha\beta}$ → can work out orbits, bending of light rays; "time delay"

(skip all eq'ns)

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(13) Gravitational Waves

sources

metric: $ds^2 = dt^2 - (1 + h(z-ct))\,dx^2 - (-)\,dy^2 - dz^2$

Action on masses: bar, interferometer

(14) Cosmology.

large scale homogeneity & isotropy

→ metric varies only in time

→ $ds^2 = dt^2 - a^2(t)\,\underbrace{(dx^2+dy^2+dz^2)}_{\text{flat}}$.

↑ scale factor

measure $a(t)$?

(b) Locally, linear: Hubble expansion

(a) redshift

distant: integrated effect.

e.g. flux (z, L)

; or angular dist:

Friedman eq'ns

$$\left(\frac{\dot a}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{k}{a^2}$$

$$\frac{\ddot a}{a} = -\frac{4\pi G}{3}(\rho + 3p)$$

$\frac{dr^2}{1-kr^2} + r^2(d\theta^2 + \sin^2\theta\, d\varphi^2)$

$k=0$ flat

$k=1$ pos. curvature: S^3

$k=-1$ neg. curv H^3

Dark "matter" & "energy"

"vacuum energy":

$T^{vac}_{\alpha\beta} = \rho^{vac} g_{\alpha\beta}$

↑ constant

locally Lorentz invariant, $p = -\rho$.