ANL Workshop on proton decay. June 82.

Rosen :

$$\tau_p \sim 10^{32\pm 2}\left(\frac{\Lambda}{2\,\mathrm{GeV}}\right)^4 \text{ yrs}$$

BR $p \to e^+\pi^0$ ~ 40%

SUSY dim 5 matrix $K^+ + \nu_e$ 100%

2nd generation expts ?

If $\tau = 10^{31} - 10^{32}$ yes

$10^{33} - 10^{34}$ Yes/No

$> 10^{34}$ No

Detector size 1 kton = 6×10^{32} protons

National underground facility ?

p decay ; $\beta\beta$; CR & gravity

Langacker :

a. Unif. mass

$\sin^2\theta$ > Standard 321 favored.

Theoretical cal. good to 1%

$$\sin^2\theta = 0.2138 \pm 0.025 + 0.004\,(n_H - 1) - 0.0004\,(n_f - 3)$$

$$0.215 \pm 0.012 \text{ exp.}$$

$$M_X = 2.4 \times 10^{14} \times (1.5)^{..} \times \left(\frac{\Lambda}{.166}\right) \times \left(\frac{1}{1.5}\right)^{n_H - 1} \times (1.2)^{n_f - 3}$$

L-R sym. theory $\sin^2\theta > .29$

$$\tau_p \sim \frac{M_X^4}{\alpha_s^2 m_p^5} \sim 2\times 10^{29} \text{ for } \begin{array}{l}\Lambda = .166 \text{ Gev} \\ M_X = 2.4\times 10^{14} \\ \alpha_s = 0.022\end{array}$$

Decay diagrams

$$\downarrow$$

$$\tau_p \sim 3.2\times 10^{29\pm1.3}\left(\frac{\Lambda}{.166}\right)^4 \rightarrow 10^{29\,{}^{+2.1}_{-2.8}}$$

$$0.8 < \frac{\tau_{pn}}{\tau_p} < 1.5$$

B.R. $e\pi^0/e\omega$ dominant.

Other models (same $\sin^2\theta$) → $10^{\pm3}$ additional uncertainty

Phenomenology $d = 6$ operators.

Gauge fields only O_1, O_2 $O_2/O_1 \equiv r$

Higgs O_3 O_4

SU_5 $r = 2$ SU_{10} ≤ 2

$e\pi^0/e\rho^0/e\eta/e\omega$ indep of r

$e/\nu \sim 1+r^2 = \dfrac{O^{16}\rightarrow e^+X}{O^{16}\rightarrow \nu X}$

μ^+X polarization also dependent.

Susy: Breaking ~ 1 Tev.

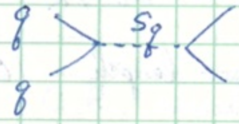
New particles → β fn, m_X, $\sin^2\theta$ change

No Higgs = $\tau_p \sim 10^{45}$ yr

2 Higgs 4.5×10^{15}

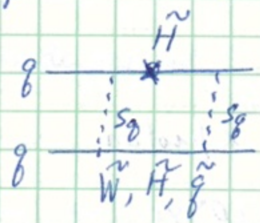
4 Higgs same as old; bad $\sin^2\theta$

d = 4 $\left(\begin{matrix} Sq \\ \tilde{W} \\ \tilde{H} \end{matrix} \right.$



$\tau_p \sim (M_x)^0$

d = 5



$\sim M_x^2$ should be suppressed.

$\Delta S = 1$ favored

$p \to K^0 \mu^+, K^+ \nu$ 40%

$n \to K^0 \nu$

$m_H \gtrsim 10^{10}$ Gev

McIntyre on monopoles

$M \sim 10^{16}$ Gev.

$\beta \sim 1.5 \times 10^{-3}$ from gravity fall in galaxy
2×10^{-3} galax. rotation
" motion of galaxy

β_{escape} 3×10^{-2}

Mag. field $B \sim B_0 r/R$ $\sim 2.5 \times 10^{-6}$ gauss
Reversal ~~time~~ length 100 pc

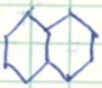
Monopole flux limits
Closing of univ. $10^{-14} \times$ proton
Mag field life $\tau \sim 10^8$ yr $\rightarrow \frac{B}{8\pi g \tau} = 5 \times 10^{-4} / m^2 yr$

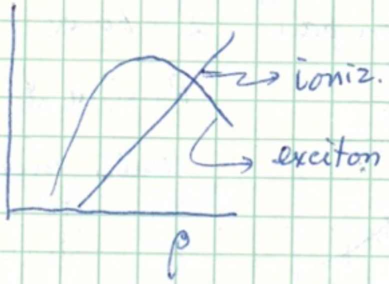
Local flux. 1 KG in ⊙ $\rightarrow \beta \sim 10^{-4}$
Flux $< 3 \times 10^{4} / m^2 yr$

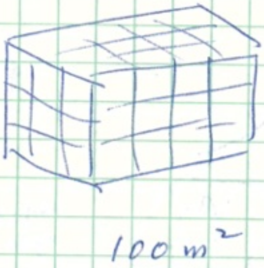
Earth 100 G. $\beta \sim 3 \times 10^{-5}$

Detection methods
Cabrera
Rubbia Thermal acoustic pulses
$dE/dx \sim 1$ Gev/cm $\Delta T \sim .2°K$
Alvarez, Cline fossils.
McIntyre Scint. Counter
$dE/dx \sim 16\beta$ Gev/cm low β
I_{min} at $\beta = 10^{-4}$, 20 Mev/g cm²

Napthalene 2.5 ev triplet excitation delay ~ 10^{-6} sec.



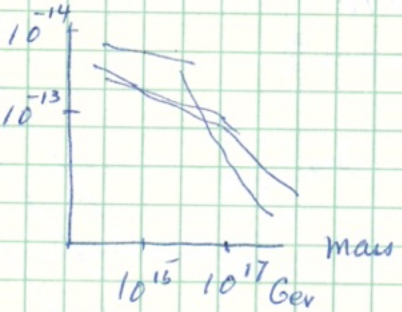


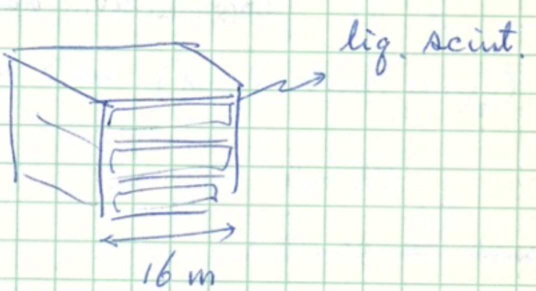


200 μsec window

Baksan, Chudakov C.R. results

300 m underground, (detect upgoing μ's)





Look for 1/4 min ion. pulses in 3000 hrs

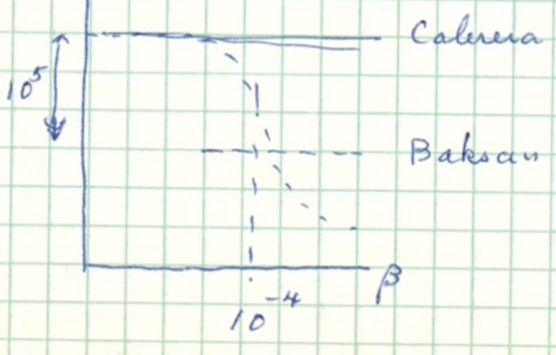
→ flux < 10^{-14}/cm² sec ster

for $0.1 < \beta < 5\times10^{-3}$

Goebel calculation: Binding in Al ~ 2 Mev.

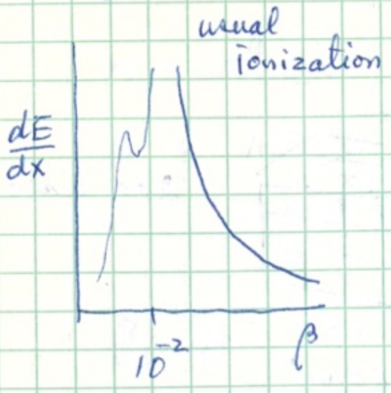
→ capture length 250 Km

Conclusion



To be compatible, $\beta < 10^{-4}$

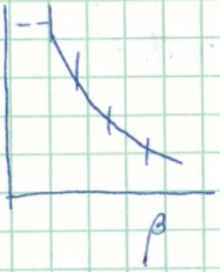
Hagstrom problems with dE/dx



Adiabatic : $\frac{dE}{dx} \sim e^{-1/v} \rightarrow v^{12}$

Energy/ion pair 2 – 60 ev.

Russian & American results incompatible



scintillator response $\beta > 10^{-3}$

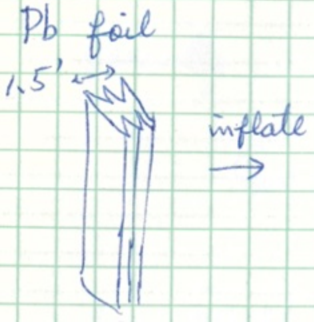
low activ. material (Ge) $\beta > 10^{-4}$

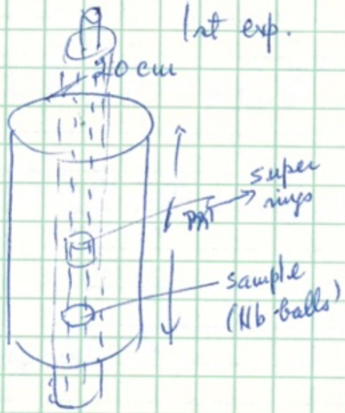
Cabrera 6/16

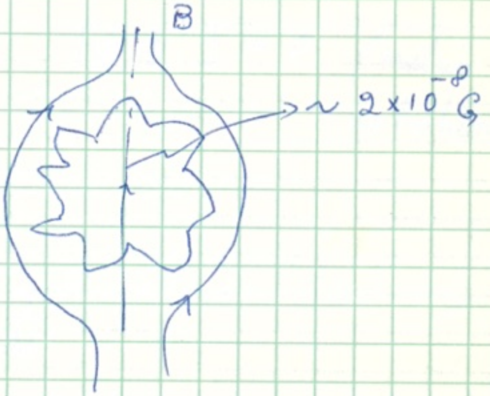
Fairbank's group working on: Ultra Low Mag Field;

Relativity gyro effects; He^3 Nuc. E.D. moment; ..

1st exp.





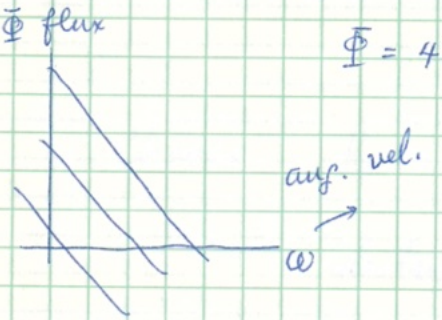


Measured sensitivity 10^{-9} G

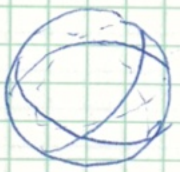
$\Phi = 4 s \omega S$ + relativistic correc. (kin. & bind. energy)
area

120 ppm for Nb

1.5 mil ~~Nb~~ Nb wire



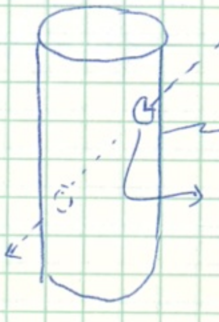
New apparatus



3 loops etched

sensitivity 8× or 40×

Next generation ~~New~~ apparatus



10^{-7} G / cm^2

Dyon. (Julia, Zee PR $\underline{\underline{D11}}$, 2227 (75))

Take the more general asymptotic ansatz

$$A_\mu = \hat{\phi} \times \partial_\mu \hat{\phi} + f_\mu \hat{\phi}$$

generally, $i\lambda \bar{\Phi} \overleftrightarrow{\partial_\mu} \bar{\Phi} + \phi f_\mu \bar{\Phi}'$ $[\bar{\Phi}, \bar{\Phi}'] = 0$ (matrix notation)

$$G_{\mu\nu} = i\lambda \underbrace{\partial_\mu \bar{\Phi}\, \partial_\nu \bar{\Phi}} + f_{\mu\nu} \bar{\Phi}'$$

For SU(5) adjoint $\bar{\Phi}$: $\lambda = \frac{1}{25}$

$(\bar{\Phi}^2 = a\mathbb{1} + b\bar{\Phi}, \quad \lambda = 4a^2 + b^2, \quad a = 6, b = -1)$

Choose $f_0 = f(r) \sim \frac{Q}{4\pi r} - M$, Q, M: parameters

electric charge $q = Q/g_e$

Dyon mass: $\sim \frac{4\pi}{g_e}\left(\frac{m}{\sqrt{\lambda}}\right)\sqrt{1 + \frac{Q^2}{g^2} g_e^2}$

$\hookrightarrow \sqrt{1 + Q^2 g_e^2}$

$4\pi \frac{m}{\sqrt{\lambda}} \sqrt{q_E^2 + g_M^2}$

Jackiw. Quantum Theory around classical sol.

~~P~~RMP 49, 681 (77)

1. Scalar scaling Lagrangian is used.

$$\text{Action} = \exp\left[-\frac{1}{g^2}\int \underset{\substack{\downarrow \\ (\partial_\mu\varphi)^2 + m^4 \underset{\substack{\downarrow \\ \text{nontrivial}}}{f}(\varphi/m)}}{L}(\partial_\mu\varphi,\ \varphi/m)\right]$$

$\exists$ finite energy static nontrivial sol in $d=1$ only. (Hobart)

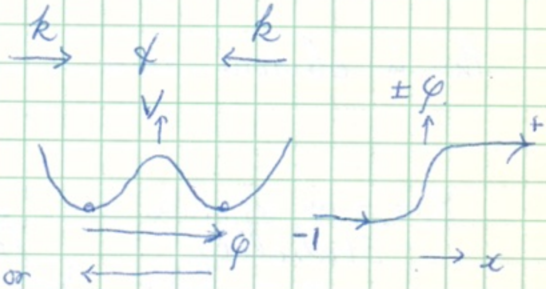
Energy of soliton $= O(1/g^2)$

2. ~~Expansion around φ_{cl} : quadratic in $\delta\varphi$.~~

φ^4 theory 2 sols

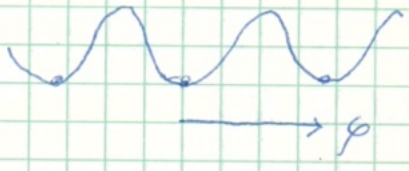
1 zero energy bound state $L = 2$

1 finite bound state

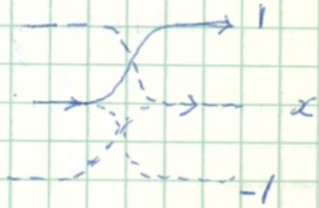


Sine-Gordon

1 ~~2~~ zero energy bound states $L = 1$.



$$\omega^2 = \begin{cases} L^2 + k^2 & \text{continuum} \\ L^2 - n^2 \end{cases}$$



Expansion around φ_{cl}.

Zero mode must be promoted to kinetic energy.

$$E_k = \sqrt{M^2+k^2} = \sqrt{\frac{C^2}{g^2}+k^2} = \frac{C}{g}\left(1+\frac{g^2}{2}\frac{k^2}{C^2}+\cdots\right)$$

$$= \frac{C}{g} + O(gk^2)$$

This means that $\varphi(p)$ and $\varphi(p')$ couple.

$$L = \int\left[\frac{1}{2}\dot{\varphi}_c^{\,2} - \frac{1}{2}(\nabla\varphi_c)^2 - V(\varphi_c)\right]d^3x$$

↳ canonical momentum.

Def. Between 2 solitons P, P'.

$$\langle P'|\varphi|P\rangle = \int e^{i(p'-p)\cdot x}\,\varphi_{cl}(x)\,d^0x$$

this is obvious since $\langle x'|\varphi|x\rangle_{cl} = \varphi_{cl}(x)\,\delta(x-x')$

Stability : Topological current $\varepsilon_{\mu\nu}\partial_\nu\varphi = J_\mu$

$$\int J_0\,dx \neq 0$$

Statistics : $\langle p'|\varphi|p\rangle$ = odd in $(p-p')$

Crossing sym → $= \langle p,-p'|\varphi|0\rangle$

↓ sol + (antisol ?

↓ True ?

Time dependent φ_c known for SG. sol-$\overline{\text{sol}}$ bound states

→ Bohr-Sommerfeld quantization.

Fluctuations around time-dependent φ_c.

Known only for SG.

Equivalence bet. SG & massive Thirring model.

$\bar{\psi}\gamma_\mu\psi \leftrightarrow \varepsilon_{\mu\nu}\partial_\nu\Phi$.

Noether ⟷ Topological

Inclusion of Fermi fields

∃ zero-energy sols. → doubling of $|\text{vac}\rangle$

fermion # $= \pm 1/2$.

In 3-dim:

Doubling of vac by fermions → fermion # $= \pm 1/2$

but spin $= 0$.

Dyon system: $\underbrace{\text{if charge}}_{\text{a boson with}} = \frac{\tau}{2}e$ → spin $= 1/2$.

Jackiw & Rebbi RMP D13, 3398 (76)

Fermion solitons 1D & 3D examples

3D in monopole field, fermion $I = \frac{1}{2}$ & 1 cases solved.

zero sols. ↓ ↓

$J = 0$ $J = \frac{1}{2}$

↓

Also exist for dyons, too.

Asymptotic $J = \frac{1}{2}$ $\psi \sim \frac{1}{r^2} \oplus e^{-\underbrace{G\mu}_{m_\infty} r}$

Christ & Jackiw. P.L. 91 B, 228 (80)

Pontryagin index $\nu = -\frac{1}{16\pi^2}\int \mathrm{Tr}\, F^{\mu\nu}\,{}^{*}F_{\mu\nu}$

applicable to monopoles ~~for a~~ with periodic time dependence.
& dyons

↓
creates pure gauge
electric effects.

Q: Aharonov-Bohm effect similar way?

Cf. G.A. Goldin ~~[illegible]~~, R. Me~~[illegible]~~nikoff & D.H. Sharp.

J. Math Phys. 22, 1664 (81)

Reps of local current algebra etc.

Monopole pair creation

A.K. Drukier & S. Nussinov. PRL 49, 102 (82)