Masses and mean lives of elementary particles; November, 1957
(The antiparticles are assumed to have the same spins, masses, and mean lives as the particles listed)

| | Particle | Spin | Mass (Errors represent standard deviation) (Mev) | Mass difference (Mev) | Mean life (sec) | Decay rate (number per second) |
|---|---|---|---|---|---|---|
| Photon | $\gamma$ | 1 | 0 | | stable | 0 |
| Leptons | $\nu$ | $\frac{1}{2}$ | 0 | | stable | 0 |
| | $e^-$ | $\frac{1}{2}$ | 0.510976 (a) | | stable | 0 |
| | $\mu^-$ | $\frac{1}{2}$ | $105.70 \pm 0.06$ (a) | | $(2.22 \pm 0.02) \times 10^{-6}$ | $0.45 \times 10^{6}$ |
| Mesons | $\pi^+$ | 0 | $139.63 \pm 0.06$ (a) | 4.6 (a) | $(2.56 \pm 0.05) \times 10^{-8}$ (a) | $0.39 \times 10^{8}$ |
| | $\pi^0$ | 0 | $135.04 \pm 0.16$ (a) | | $< 4 \times 10^{-16}$ (d) | $> 2.5 \times 10^{15}$ |
| | $K^+$ | 0 | $494.0 \pm 0.2$ (g) | $0.4 \pm 1.8$ | $(1.224 \pm 0.013) \times 10^{-8}$ (h) | $0.815 \times 10^{8}$ |
| | $K^0$ | 0 | $494.4 \pm 1.8$ (i) | | $K_1$: $(0.95 \pm 0.08) \times 10^{-10}$ (e) | $1.05 \times 10^{10}$ |
| | | | | | $K_2$: $(4 < \tau < 13) \times 10^{-8}$ (c) | $(0.07 < \tau < 0.25) \times 10^{8}$ |
| Baryons | p | $\frac{1}{2}$ | $938.213 \pm 0.01$ (a) | | stable | 0.0 |
| | n | $\frac{1}{2}$ | $939.506 \pm 0.01$ (a) | | $(1.04 \pm 0.13) \times 10^{+3}$ (a) | $0.96 \times 10^{-3}$ |
| | $\Lambda$ | $\frac{1}{2}$ | $1115.2 \pm 0.14$ (j) | | $(2.77 \pm 0.15) \times 10^{-10}$ (k) | $0.36 \times 10^{10}$ |
| | $\Sigma^+$ | $\frac{1}{2}$ | $1189.4 \pm 0.25$ (l) | $7.1 \pm 0.4$ | $(0.83 {}^{+.06}_{-.05}) \times 10^{-10}$ (m) | $1.21 \times 10^{10}$ |
| | $\Sigma^-$ | $\frac{1}{2}$ | $1196.5 \pm 0.5$ (n) | $6.0^{+1.4}_{-0.9}$ | $(1.67 \pm 0.17) \times 10^{-10}$ (o) | $0.60 \times 10^{10}$ |
| | $\Sigma^0$ | $\frac{1}{2}$ | $1190.5^{+0.9}_{-1.4}$ (p) | | $(< 0.1) \times 10^{-10}$ (b) theoretically $\sim 10^{-19}$ | $> 10 \times 10^{10}$ theoretically $\sim 10^{19}$ |
| | $\Xi^-$ | ? | $1320.4 \pm 2.2$ (q) | | $(4.6 < \tau < 200) \times 10^{-10}$ (f) | $(> 0.005, < 0.2) \times 10^{10}$ |
| | $\Xi^0$ | ? | ? | | ? | |

## Table IV

Atomic and nuclear constants in units of Mev, cm, and sec[a]

### GENERAL ATOMIC CONSTANTS

$N = 6.0249 \times 10^{23}$ molecules/gram

$c = 2.99793 \times 10^{10}$ cm/sec

$e = 4.80286 \times 10^{-10}$ esu $= 1.6021 \times 10^{-19}$ coulomb.

1 Mev $= 1.6021 \times 10^{-6}$ erg [1 ev $= e(10^8/c)$]

$\hbar = 6.5817 \times 10^{-22}$ Mev sec $= 1.054 \times 10^{-27}$ erg sec.

$\hbar c = 1.9732 \times 10^{-11}$ Mev cm [$= \lambda\!\!\!^{-}$ for p = 1 Mev/c]

$k = 8.6167 \times 10^{-11}$ Mev/°C [Boltzmann constant]

$\alpha = \frac{e^2}{\hbar c} = 1/137.037$; $e^2 = 1.44 \times 10^{-13}$ Mev cm

### QUANTITIES DERIVED FROM THE ELECTRON MASS, m

**Mass and Energy**

$m = 0.510976$ Mev $= 1/1836.12\ m_p = 1/273.26\ m_\pi$

Rydberg, $R_\infty = \frac{me^4}{2\hbar^2} = mc^2 \times \frac{\alpha^2}{2} = 13.605$ ev

**Length** (1 fermi $= 10^{-13}$ cm; 1 Å $= 10^{-8}$ cm)

$r_e = e^2/mc^2 = 2.81785$ fermi

$\lambda\!\!\!^{-}_{Compton} = \frac{\hbar}{mc} = r_e \alpha^{-1} = 3.8612 \times 10^{-11}$ cm

$a_\infty$ Bohr $= \frac{\hbar^2}{me^2} = r_e \alpha^{-2} = 0.52917$ Å

**Cross Section**

$\sigma_{Thompson} = \frac{8}{3} \pi r_e^2 = 0.6652 \times 10^{-24}$ cm$^2$ $= 0.6652$ barn

### Magnetic Moment and Cyclotron Angular Frequency

$\mu_{Bohr} = \frac{e\hbar}{2mc} = 0.57883 \times 10^{-14}$ Mev/gauss

$\frac{1}{2}\omega_{cyclotron} = \frac{e}{2mc} = 8.7945 \times 10^{6}$ rad sec$^{-1}$/gauss

$g_{electron} = 2[1 + \frac{\alpha}{2\pi} + 0.328 (\frac{\alpha}{\pi})^2] = 2[1.001163]$[b]

$g_{muon} = 2[1 + \frac{\alpha}{2\pi} + 0.75 (\frac{\alpha}{\pi})^2] = 2[1.001172]$[b]

### QUANTITIES DERIVED FROM THE PROTON MASS, $m_p$

Rest mass $= 938.211$ Mev/c$^2$ $= 1836.12\ m_e = 6.719\ m_\pi$

$= 1.007593\ m_I (m_1 = 1$ amu $= \frac{1}{16} O^{16})$

### Magnetic Moment and Cyclotron Angular Frequency

$\mu_p = \frac{e\hbar}{2m_p c} = 3.1524 \times 10^{-18}$ Mev/gauss

$\frac{1}{2}\omega_{cyclotron} = \frac{e}{2m_p c} = 4.7896 \times 10^{3}$ rad sec$^{-1}$/gauss

$g_p \equiv \left.\frac{\mu}{\mu_p}\right)_{proton} = 2.79275$; $g_n \equiv \left.\frac{\mu}{\mu_p}\right)_{neutron} = -1.9128$

(continued below)

## Table IV (continued)

### QUANTITIES DERIVED FROM THE MASS OF THE CHARGED PION, $m_\pi$

**Rest mass** $= 139.63$ Mev/c$^2$ $= 273.26\ m_e = 0.14882\ m_p$

**Length**

$\frac{\hbar}{m_\pi c} = 1.4132$ fermi ($\sim\sqrt{2}$ fermi)

**Natural (≈ "geometrical") Nucleon Cross Section**

$\pi \left(\frac{\hbar}{m_\pi c}\right)^2 = 62.7344$ mb (1 mb $= 10^{-27}$ cm$^2$)

**(3/2, 3/2) $\pi$p Resonance**

Center-of-mass momentum: $p_\pi = 230$ Mev/c

Lab-system momentum: $P_\pi = 303$ Mev/c ($T_\pi = 194$ Mev)

### RADIOACTIVITY

1 curie $= 3.7 \times 10^{10}$ disintegrations/sec

1 r $= 87.8$ ergs/g air $= 5.49 \times 10^{7}$ Mev/g air

Fluxes (per cm$^2$) to liberate 1 r in carbon:

$3 \times 10^{7}$ minimum ionizing singly charged particles
$0.9 \times 10^{9}$ photons of 1 Mev energy.

(These fluxes are are actually correct to within a factor of two for all materials.)

Natural background: 100 mr/year

"Tolerance" 100 millirem/week [Note, 1 r may produce up to 10 "rem" (r equivalent for man), depending on type of radiation.]

### MISCELLANEOUS

**Physical Constants**

1 year $= 3.1536 \times 10^{7}$ sec ($\approx \pi \times 10^{7}$ sec)

Density of air $= 1.205$ mg/cm$^3$ at 20°C

Acceleration by gravity $= 980.67$ cm/sec$^2$

1 calorie $= 4.184$ joules

1 atmosphere $= 1033.2$ g/cm$^2$

**Numerical Constants**

1 radian $= 57.29578$ deg; $e = 2.71828$
$\ln 2 = 0.69315$; $\log_{10} e = 0.43429$;
$\ln 10 = 2.30259$; $\log_{10} 2 = 0.30103$.

**Stirling's approximation**

$\sqrt{2\pi n} \left(\frac{n}{e}\right)^n < n! < \sqrt{2\pi n} \left(\frac{n}{e}\right)^n \left(1 + \frac{1}{12n - 1}\right)$

**Gaussianlike Distributions**

For $n > -1$ but not necessarily integral:

$\int_0^\infty x^{2n+1} \exp\left[-\frac{x^2}{2\sigma^2}\right] dx = 2^n\, n!\, \sigma^{2n+2}$; $(\frac{1}{2})! = \sqrt{\pi}/2$

Relation between standard deviation $\sigma$ and mean deviation $\alpha$:

$2\sigma^2 = \pi\alpha^2$; $\sigma = 1.4826$ probable error.

Odds against exceeding one standard deviation $= 2.15:1$ two, 21:1; three, 370:1; four, 16,000:1; five, 1,700,000:1

[a] Based mainly on Cohen, Crowe, and Dumond, The Fundamental Constants of Physics (Interscience, New York, 1957).

[b] C. Sommerfield, Phys. Rev. 107, 328 (1957).

Table II

Atomic and nuclear properties (dE/dx, collision mean free path, radiation length, etc.) of materials used as absorbers and detectors

| Material | Z | A | Cross section $\sigma$ [a] (barns) | $\frac{dE}{dx}$ [b] min $\frac{\text{Mev}}{\text{g/cm}^2}$ | Collision [a] length, $L_{coll}$ g/cm² | Collision [a] length, $L_{coll}$ cm | Radiation [c] length, $L_{rad}$ g/cm² | Radiation [c] length, $L_{rad}$ cm | Density $\rho$ (g/cm³) |
|---|---|---|---|---|---|---|---|---|---|
| $H_2$ | 1 | 1.01 | 0.063 | 4.14 | 26.5 | 374 | 58 | 819.0 | 0.0708 |
| Li | 3 | 6.94 | 0.23 | 1.72 | 50.4 | 94.3 | 77.5 | 145 | 0.534 |
| C | 6 | 12.00 | 0.33 | 1.86 | 60.4 | 39.0 | 42.5 | 27.4 | 1.55 (variable) |
| Al | 13 | 26.97 | 0.57 | 1.66 | 79.2 | 29.3 | 23.9 | 8.86 | 2.70 |
| Cu | 29 | 63.57 | 1.00 | 1.45 | 105.4 | 11.8 | 12.8 | 1.44 | 8.9 |
| Sn | 50 | 118.70 | 1.55 | 1.27 | 129.7 | 17.8 | 8.54 | 1.17 | 7.30 |
| Pb | 82 | 207.21 | 2.20 | 1.12 | 156.2 | 13.8 | 5.8 | 0.51 | 11.34 |
| U | 92 | 238.07 | 2.42 | 1.095 | 163.6 | 8.75 | 5.5 | 0.29 | 18.7 |
| Hydrogen (bubble chamber, -27.6°K) | | | | 0.243 Mev/cm | 26.5 | 452 | 58 | 990 | 0.0586 |
| Propane ($C_3H_8$, bubble chamber) | | | | 0.935 Mev/cm | 48.9 | 119.3 | 44.7 | 109.0 | 0.41 |
| Polystyrene (CH scintillator) | | | | 2.14 Mev/cm | 54.9 | 52.3 | 43.4 | 41.3 | ~ 1.05 |
| Ilford emulsion | | | | 5.49 Mev/cm | 103 | 27.0 | 11.2 | 2.91 | 3.815 |

Table III

Multiple scattering (Coulomb only) calculated from Molière theory.

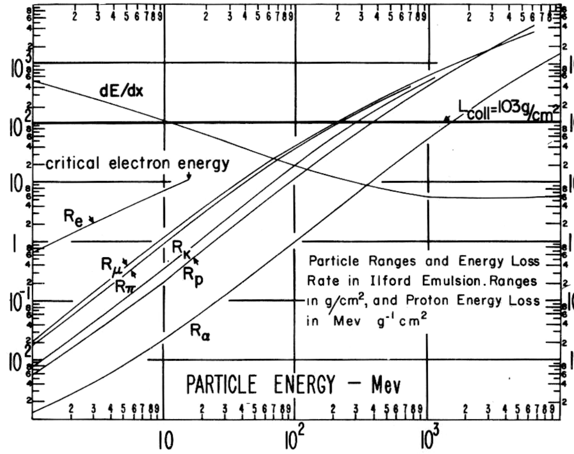
$\theta_{mp}$ is the mean projected angle in radians between tangents to the particle trajectories:

$$|\theta|_{\text{average}} \equiv \theta_{mp} = z\,\frac{12(\text{Mev})}{pv(\text{Mev})}\sqrt{\frac{L}{L_{rad}}}\,(1+\epsilon) \quad *$$

L is the thickness, and $L_{rad}$ the radiation length (from Table II) for the absorber (atomic number Z). For particles of charge ze and velocity $\beta c$, the following table for $\epsilon$ applies:

| Z \ $L/L_{rad}$ | $10^{-3}$ | $10^{-2}$ | $10^{-1}$ | 1 | 10 | |
|---|---|---|---|---|---|---|
| 1 | -0.20 | -0.14 | -0.08 | -0.03 | +0.02 | |
| 6 | -0.14 | -0.07 | -0.00 | +0.06 | +0.12 | $\beta/z$ = 0.1 |
| 29 | -0.18 | -0.10 | -0.01 | +0.06 | +0.13 | (4.7-Mev proton) |
| 82 | -0.27 | -0.16 | -0.07 | +0.02 | +0.10 | |
| 1 | -0.26 | -0.20 | -0.14 | -0.08 | -0.03 | |
| 6 | -0.20 | -0.12 | -0.05 | +0.01 | +0.07 | $\beta/z$ = 0.3 |
| 29 | -0.20 | -0.11 | -0.03 | +0.05 | +0.12 | (45-Mev proton) |
| 82 | -0.28 | -0.17 | -0.07 | +0.08 | +0.09 | |
| 1 | -0.31 | -0.24 | -0.18 | -0.12 | -0.07 | |
| 6 | -0.26 | -0.18 | -0.10 | +0.03 | +0.03 | $\beta/z$ = 0.7 |
| 29 | -0.25 | -0.15 | -0.06 | +0.02 | +0.09 | (380-Mev proton) |
| 82 | -0.29 | -0.17 | -0.08 | -0.01 | +0.09 | |
| 1 | -0.34 | -0.26 | -0.20 | -0.14 | -0.08 | |
| 6 | -0.29 | -0.20 | -0.12 | -0.05 | -0.01 | $\beta/z$ = 1.0 |
| 29 | -0.34 | -0.23 | -0.13 | -0.05 | -0.03 | |
| 82 | -0.31 | -0.19 | -0.09 | -0.00 | -0.08 | |

*Note that in the Gaussian approximation the root-mean-square projected angle is obtained from the formula above by substituting 15 for the coefficient 12.

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