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Table of Properties of the "Elementary" Particles*

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INTRODUCTION

DURING the years 1949 through 1954 at least eight different K mesons[1] or K-particle decay modes and at least four different hyperons (Y particles)[1] were discovered. During the past year no new mesons or hyperons have been found, but much has been learned about the known ones. A table of the properties of these particles is thus frequently needed by both specialists and nonspecialists in this field.

The present table was made as comprehensive and up-to-date as was possible, although a detailed analysis of every pertinent experiment was not attempted.[2] The table was compiled for private laboratory and course use, and time has not permitted an extensive revision. The principal journals in the field were quite thoroughly searched through February, 1956, although only a minimum number of references have been listed. In many instances a given value is a roughly weighted average of many experimental measurements, even though reference is made to only one or two of these experiments. No criticism is implied of the experiments not mentioned; the listed references generally reported either the most recent or most precise experiments or gave comprehensive summaries of the data. References to practically all other experiments can be found in the listed ones.

A detailed analysis of the experimental evidence and its implications will not be presented here. Several excellent review articles and reports of conferences are available.[3]

EXPLANATORY REMARKS

In Sections I and II of the table, only those particles are listed which have been quite thoroughly studied by more than one group of experimenters. A third part is appended which includes less well-established particles and particles which are expected to exist, on theoretical grounds.

Even the well-established particles may have some characteristics which are not well determined. This is indicated in the table by placing parentheses around these entries. A question mark is also frequently used to emphasize the uncertainty. As an example, it is known that negative K mesons exist, but it is not definitely known which of the K^+ particles listed in Sec. II, if not all, have negative counterparts.† This uncertainty is indicated by placing a parenthesis around the minus sign in each case.

The value of the π-meson mass is of crucial importance throughout the table. As an example of this, the masses of all the listed hyperons were determined by adding the measured decay energies (Q values) to the masses of the decay products, which include a pion in each case. The table is based on a value of $273.1\pm0.2\,m_e$ for the mass of the charged pion. It is assumed that the π^+ and π^- mesons have equal masses. This value is a weighted average of the values $273.4\pm0.2\ m_e$ and $272.5\pm0.3\ m_e$ determined for the π^+ and π^- mesons, respectively, by Smith, Birnbaum, and Barkas.[4] After the compilation of the table was completed, a final report by Barkas, Birnbaum, and Smith was published[5] with revised masses of $273.3\pm0.2\ m_e$ and $272.8\pm0.3\ m_e$ for the positive and negative pion. The measurement of the π^- mass ($272.7\pm0.3\ m_e$) by Crowe and Phillips should also be included.[6] Since the new weighted average is hardly different from $273.1\pm0.2\ m_e$, this latter value is retained throughout the table.

Many experimenters have used somewhat different values for the mass of the charged pion, and this accounts for part of the spread in their derived masses of the hyperons and K particles. It would obviously be best if everyone would use the same mass value, and we propose that $273.1\pm0.2\ m_e$ be used.

SECTION I. ESTABLISHED PARTICLES

A. Grouping of Particles

The eighteen "elementary" particles listed in Sec. I (counting the positive and negative particles separ-

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[1] Amaldi, Anderson, Blackett, Fretter, LePrince-Ringuet, Peters, Powell, Rochester, Rossi, and Thompson, Nature **173**, 123 (1954); Nuovo cimento **11**, 213 (1954).

[2] Many excellent tables have been prepared in the past. The basic format of the present table is similar to that of an earlier one prepared by Professor B. Rossi. *Note added in proof.*—A table of the mesons and hyperons has just been published by M. M. Shapiro (Am. J. Phys. **24**, 196 (1956)). This paper contains a quite complete bibliography of the literature up to the middle of 1955.

[3] See, for example, independent summaries by R. E. Marshak and R. W. Thompson of the 1955 International Conference on Elementary Particles at Pisa (unpublished); Mimeographed Proceedings of the International Conference on Elementary Particles, Pisa, June, 1955 [Nuovo cimento (to be published)]; Part I, Session 3 of the Varenna Lectures, Nuovo cimento, Suppl. No. 1, 2, 163–274 (1955); *Proceedings of the Fifth Annual Rochester Conference, 1955* (Interscience Publishers, Inc., New York, 1955); *Proceedings of the 1954 Glasgow Conference on Nuclear and Meson Physics* (Pergamon Press, London and New York, 1955); several review articles in volumes of the *Annual Review of Nuclear Science*, *Progress in Cosmic Ray Physics*, and the *Reports on Progress in Physics*.

† See Appendix added in proof. This symbol, used throughout the text, indicates that qualifying comments have been added in the Appendix.

[4] Smith, Birnbaum, and Barkas, Phys. Rev. **91**, 765 (1953).

[5] Barkas, Birnbaum, and Smith, Phys. Rev. **101**, 778 (1956).

[6] K. M. Crowe and R. H. Phillips, Phys. Rev. **96**, 470 (1954).

ately) are divided into five groups.[1] In the first group are placed all particles with rest masses less than or equal to that of the electron. The other groups are determined as follows:

$$\begin{aligned} &L\text{ mesons:} && m_e < m_{L\text{ meson}} \leqslant m_{\pi^\pm};\\ &K\text{ mesons:} && m_{\pi^\pm} < m_{K\text{ meson}} < m_{\text{proton}};\\ &\text{Nucleons:} && \text{the proton and the neutron};\\ &\text{Hyperons:} && m_{\text{neutron}} < m_{\text{hyperon}} < m_{\text{deuteron}}. \end{aligned}$$

A sixth group consisting of the nonelementary deuteron, triton, and He^3 nucleus was included primarily to indicate the binding energies and magnetic moments of small assemblies of nucleons.

B. Errors

If the positive and negative errors associated with a number are equal, the error is placed in parentheses beneath those digits of the number which are uncertain; if the errors are unequal, the positive error is placed in parentheses above the uncertain digits and the negative error below them. For example, -1.001146 ± 0.000012 is presented as $-1.001\underset{(12)}{146}$, and $\left(1.3^{+0.4}_{-0.3}\right)\times 10^{-10}$ as $\overset{(4)}{\underset{(3)}{1.3}}\times 10^{-10}$.

The errors listed are unfortunately a mixture of standard deviations and probable errors. Since many authors do not specify which type they are using, the policy was adopted of using the error listed in the most precise experiment.

C. References

In Section I of the table, references are indicated by small letters of the English alphabet placed as superscripts or subscripts at the right of the quantity in question. The reference letter is normally placed as a superscript; however, when the quantity contains a power of ten, the letter is placed as a subscript in order to avoid confusion with the exponent.

For the sake of conciseness and clarity, no reference symbols have been placed in columns 6, 12, 13, and 14, and only one in each of columns 9 and 11. The sources of the information listed in these columns can be found in the articles of reference 3. The discovery and verification of the decay schemes, and the determination of these quantized properties, are some of the most fascinating aspects of this field.

In the case of the unstable particles, either the mass of the parent particle is measured and the Q value of its decay is derived from the known masses, or else the Q value is measured and the mass of the parent is derived from it plus the known masses of the decay products. In either situation, the reference letter is always placed next to the measured quantity, and the derived nature of the remaining quantity is indicated by the absence of reference symbols.

D. Description of the Columns, and Comments

Column 1

In this column are listed the most commonly used symbols of the particles, and their charges. The charge is indicated at the upper right of each symbol. The entries which are definitely not elementary particles are placed in parentheses.

Columns 2, 3, 4, and 5

These columns contain the masses of the particles in the indicated units. Strictly speaking, column 5 presents their rest or proper energies, not masses.

In the lower half of column 2 of the table, the listed mass values are those calculated by Wapstra.[7] It is the consensus of experts in this field that these are the most accurate and consistent set of values presently available. Note that, with the exception of (H^1), the values listed are the *nuclear* masses, not atomic masses.

For the deuteron, triton, and He^3 nucleus the corresponding binding energy, B.E., is presented in columns 3, 4.

Column 6

Herein are listed the known decay schemes of the particles. Only two of the particles, the π^0 and the Σ^+, are known with certainty to have more than one decay mode.† It is thought, also, that the $K_{\pi 3}$ or τ' particle is a τ meson decaying in an alternate mode.

π^0.—In addition to its usual decay into two photons, the neutral pion is known to decay also into a photon and an electron-positron pair. This is known to occur about once in eighty decays.[8,9] It is thus expected that about once in $(160)^2$ decays, the π^0 will decay directly into two electron-positron pairs. There is evidence that this process does occur in a cloud-chamber event observed by Hodson *et al.*[10]

Σ.—It has been verified that there are hyperons which have the following three decay modes:

$$Y^+ \rightarrow p + \pi^0 + \sim 116 \text{ Mev}, \tag{1}$$

$$Y^+ \rightarrow n + \pi^+ + \sim 110 \text{ Mev}, \tag{2}$$

and

$$Y^- \rightarrow n + \pi^- + \sim 110 \text{ Mev}. \tag{3}$$

The masses of these particles are thus about 2327 m_e, and it is tentatively assumed that they are the positive and negative components of an isotopic spin triplet called the Σ hyperon. This is still to be proven (see the comments on column 8).†

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[7] A. H. Wapstra, Physica **21**, 367 (1955).

[8] Lindenfeld, Sachs, and Steinberger, Phys. Rev. **89**, 531 (1953).

[9] R. H. Dalitz, Proc. Phys. Soc. (London) **A64**, 667 (1951).

[10] Hodson, Ballam, Arnold, Harris, Rau, Reynolds, and Treiman, Phys. Rev. **96**, 1089 (1954).

In addition to the known decay schemes, for some particles a possible or conjectured decay scheme is also listed in parentheses.

Column 7

The Q value in a given row is the total kinetic energy, measured in the rest system of the parent particle, of the decay products preceding it in the same row. This value is also equal, of course, to the difference between the rest energy of the parent particle and the sum of the rest energies of the decay products.

$\pi^{\pm}$.—The values for the π^+ and π^- mesons are presented separately, although we believe that the average value of 34.0 ± 0.2 Mev is more probably the correct one.

For the K mesons and hyperons the energies of the decay products, when determined from their ranges in nuclear emulsions and multiplate cloud chambers, are subject to uncertainty in the range-energy relation, in addition to other experimental errors. Allowance is made for this uncertainty in the errors listed.

Column 8

The mean life of each particle, in seconds unless otherwise noted, is listed in column 8.

θ^0.—The value listed for the mean life of the θ^0 is actually the mean life of all K^0 mesons observed in the experiments analyzed by Gayther[11] and Page.[12] It is believed that the particles observed were predominately θ^0's, but if an appreciable number of other kinds of K^0 mesons were present, the θ^0 mean life may be somewhat different.†

$\Sigma^{\pm}$.—It is not determined yet whether the Σ^+ and Σ^- hyperons have identical mean lives (or, for that matter, identical masses). Since, on the Gell-Mann and Pais scheme of the K mesons and hyperons,[13] the Σ^- is not thought to be the antiparticle of the Σ^+, one would not necessarily expect their lifetimes (or masses) to be identical. There is some evidence that the mean life of the Σ^- may be greater than 3.4×10^{-11} sec.[14],†

Columns 9, 11, 12, and 13

These columns present the known information on the spin, parity, total isotopic spin quantum number T, and its z or third component T_z, respectively. Discussions of these properties of the particles and the corresponding experimental evidence may be found in the articles of reference 3, as well as in the current literature.

Note that in column 9 the abbreviations Int. and $\frac{1}{2}$ Int. stand for integral and half-integral spins, respectively.

It is believed that all particles with integral spins obey Bose-Einstein statistics, while those with half-integral spins obey Fermi-Dirac statistics.

Column 10

In this column are presented the measured magnetic moments of the particles. Note that the unit used changes from the Bohr magneton in the upper half, to the nuclear magneton in the lower half.

Since the magnetic moments of the neutron, deuteron, triton, and He^3 nucleus are measured relative to that of the proton, it is usual to state the error in their values as though the proton's moment were known with zero error. This practice has been followed in the present table. In order to obtain the absolute errors, the listed errors for these four particles must be properly combined with the error in the proton's magnetic moment.

Column 14

This column, labeled Gell-Mann's S for brevity, lists the values of a possible new quantum number, a number which may be an intrinsic property of each type of particle. This number is frequently called the "strangeness" of the particle and is given the symbol S.[15] The usefulness of the "strangeness" concept (and the selection rules associated with it) lies in its ability to correlate qualitatively the main features of the production, interaction, and decay of the K particles and hyperons,[16] as well as to make successful predictions. Similar ideas have been presented by others,[17] and references 13 and 17 contain a partial list of the papers in this field. See also the articles listed in reference 3 for discussions of this concept.

SECTION II. PARTICLES WITH PROPERTIES NOT WELL DETERMINED

The particles contained in this section have all been more or less thoroughly studied and are quite well established. The negative or antiproton is placed in this section because of its newness and because many of its properties have yet to be determined.† The K

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[11] D. B. Gayther, Phil. Mag. **45**, 570 (1954); **46**, 1362 (1955).

[12] D. I. Page, Phil. Mag. **46**, 103 (1955).

[13] M. Gell-Mann and A. Pais, *Proceedings of the 1954 Glasgow Conference on Nuclear and Meson Physics* (Pergamon Press, London, 1955).

[14] Schneps, Swami, Fry, and Snow, Bull. Am. Phys. Soc. Ser. II, **1**, 64 (1956).

[15] M. Gell-Mann, Lectures at Massachusetts Institute of Technology and Harvard, 1955 (unpublished).

[16] For example, the copious production of the heavy unstable particles (K mesons and hyperons) is allowed by the conservation of the total S value of the system (resulting in their "associated production"). The slowness of the decay of these particles results from the necessity for the S value to change in the decay by ±1.

The relation between the charge value $(q/|e|)$ of a particle and the z component of its isotopic spin, T_z, is given by the equation

$$(q/|e|)=T_z+\frac{M}{2}+\frac{S}{2},$$

where S is the "strangeness" number of the particle, and M is its baryon number ($M=+1$ for nucleons and hyperons, 0 for all lighter particles, and -1 for antinucleons and antihyperons).

[17] A. Pais, Physica **19**, 869 (1953); M. Gell-Mann, Phys. Rev. **92**, 833 (1953); Nuovo cimento (to be published); T. Nakano and K. Nishijima, Progr. Theoret. Phys. (Japan) **10**, 581 (1953); M. Goldhaber, Phys. Rev. **92**, 1297 (1953); **101**, 433 (1956); D. C. Peaslee, Nuovo cimento **12**, 943 (1954); J. Rayski, Nuovo cimento **12**, 945 (1954); R. G. Sachs, Phys. Rev. **99**, 1573 (1955).

particles are placed here because it is not yet known which of these particles are just alternate decay modes of which fundamental K mesons. At the present time it is hoped and expected that there are no more than two basic K particles, the τ and the θ, but this is still to be established.

References to the literature are indicated by two small English letters.

A. Explanation of the K-Particle Symbols

The K particles in Sec. II are primarily symbolized by the letter K followed by a subletter and a subnumeral. All of these particles decay into one charged particle and one or more neutral particles. The subletter identifies the nature of the charged secondary particle. The subnumeral 2 indicates a two-body decay, i.e., only one neutral secondary particle in addition to the charged one; the subnumeral 3 indicates that at least two neutral particles are emitted.

B. Description of the Columns, and Comments

Columns 1 and 2

To the right of the particle symbol of the $K_{\pi 2}$, $K_{\pi 3}$, and $K_{\mu 3}$ is presented the Greek symbol (χ, τ', and κ, respectively) by which the particular decay mode is frequently designated. (According to convention,[1] a Greek symbol should not be used to designate solely a decay mode, but should be reserved for a "true" particle.)

The second column contains the probable modes of decay. The first three are quite well established, while the modes for the last two particles are uncertain. Beneath them in parentheses are listed possible alternative decay schemes.

Column 3

Because of the spread in the measured masses of the K particles, several values have been listed for each one, as determined in some of the most recent and precise experiments. The associated errors have been adjusted to be standard deviations for purposes of comparison. These errors are based primarily on the statistical uncertainties. To the right of the errors are symbols which indicate the method used in determining the masses.

Beneath the several representative mass values listed for each K particle, a weighted average (of all available measurements) is placed together with its standard deviation, and this is indicated by the symbol "Av."

Column 4

Herein are listed the mean lives of the particles. The errors indicated in this column are standard deviations.

Columns 5, 6, 7, 8, and 9

These columns contain values of the Q of the decay, the kinetic energy E, the momentum p, $\beta(=v/c)$ times the momentum p, and the range R of the charged secondary, calculated under the assumptions that the mass of the K particle is exactly 966 m_e and that it decays at rest into the products listed in column 2. These are calculated, not measured, values.

Column 10

It has been noted in several of the experiments which have studied the properties of the K particles that, regardless of the method of production of the particles and the conditions of the experiments, the relative frequencies of the particles decaying into the various modes are approximately the same. These branching fractions may thus be an intrinsic property of the K particles and they are listed in column 10.

SECTION III. LESS WELL-ESTABLISHED PARTICLES

1. τ^0 and Other K^0 Particles

It is reasonable to expect that there may be neutral τ mesons as well as charged τ mesons. (The existence of the τ^0 is predicted by the "strange" particle schemes.[13,17]) This meson might have either or both of the following decay schemes:

$$\tau^0 \rightarrow \pi^+ + \pi^- + \pi^0,$$
$$\tau^0 \rightarrow \pi^0 + \pi^0 + \pi^0.$$

It has been frequently pointed out that some (but not all) of the so-called anomalous V^0 events may be examples of the former decay mode.[18] There is, however, no detailed evidence in support of the τ^0 meson. It might, of course, also have other modes of decay.

Besides the θ^0 and τ^0 there may also be other K^0 mesons. At present, however, it is believed that there should be no other neutral K particles, although there may be other decay modes for these two particles. These other decay schemes may possibly explain some of the remaining anomalous V^0 events. It is postulated[19] that the following decay schemes would account for most of these events:

$$K^0 \rightarrow \pi^+ + \pi^- + \gamma,$$
$$K^0 \rightarrow \mu^\pm + \pi^\mp + \nu,$$
$$K^0 \rightarrow e^\pm + \pi^\mp + \nu.\dagger$$

2. Σ^0 and Ξ^0

In addition to the $\Sigma^\pm$ there may also exist a Σ^0 hyperon. This is predicted by those "strange" particle schemes[13,17] which assign a total isotopic spin of 1 to the Σ and thus make it a triplet family. There is no direct evidence for this particle, but its existence is implied

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[18] See, for example, R. W. Thompson's summary of the 1955 Pisa Conference; R. W. Thompson, *Progress in Cosmic Ray Physics*, edited by J. G. Wilson (to be published), Vol. 3; and the other articles listed in reference 3.

[19] See, for example, Ballam, Grisaru, and Treiman, Phys. Rev. **101**, 1438 (1956).

Table of Properties of the "Elementary" Particles

(Revised April, 1956).

I. Established particles.

	Particle	Mass				Decay products	Q	Mean life	Spin	Magnetic moment	Parity	Isotopic spin		Gell-Mann's
	Symbol and charge	$(\frac{1}{16}O^{16})$[a]	(g)[a]	(m_e)	(Mev)		(Mev)	(sec)	$(\hbar)$	$\left(\mu_0=\frac{e\hbar}{2m_ec}\right)$		T	T_z	S
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	γ^0	0	0	0	0	stable	0	∞	1					
	ν^0			<0.0005	<250 ev[b]	stable	0	∞	$(\frac{1}{2})$	$<10^{-7}$[c]				
	e^-	0.000548763 *(6)*	9.1083×10^{-28} *(3)*	1	0.510976[a] *(7)*	stable	0	∞	$\frac{1}{2}$	−1.001146[d] *(12)*				
	e^+	Same as electron to within 0.0071%[e]				$e^++e^-\rightarrow n\gamma$ $n=1, 2, 3\cdots$		^3S positronium: 1.5×10^{-7}[f] *(15)*	$\frac{1}{2}$	(+1.001146) *(12)*				
L mesons	$\mu^\pm$			206.7[g] *(2)*	105.6 *(1)*	$e^\pm+\nu+\nu$	105.1 *(1)*	2.22×10^{-6}[h] *(2)*	$(\frac{1}{2})$					
	π^+	Average $m\pi^\pm=273.1\ m_e$ *(2)* Average $m\pi^\pm c^2$ $=139.5_5$ Mev *(1)*		273.3[g] *(2)*	139.7 *(1)*	$\mu^++\nu$	34.1 (1_5)	2.53×10^{-8}[i] *(10)*	0		−	1	+1	(0)
	π^-			272.8[g] *(3)*	139.4 (1_5)	$\mu^-+\nu$	33.8 *(2)*	2.55×10^{-8}[j] *(19)*	0		−	1	−1	(0)
	π^0	$m\pi^--m\pi^0=8.8\ m_e$[k] *(6)*		264.3 *(7)*	135.0 *(3)*	$\gamma+\gamma$ $\left(\frac{1}{80}\right)\gamma+e^++e^-$ $\left(\frac{1}{160^2}\right)2e^++2e^-$	135.0 *(3)*	$(1-5)\times10^{-15}$[l]	0		−	1	0	(0)
K mesons	τ^+			966.1 *(2)*	493.7 *(1)*	$\pi^++\pi^++\pi^-$ $(\pi^++\pi^0+\pi^0)$	75.0[m] *(8)*	*(12)* 1.27×10^{-8}[n] *(2)*	(0)[m]		(−)[m]		$(+\frac{1}{2})$	(+1)
	τ^-			(966.1) *(2)*	(493.7) *(1)*	$\pi^-+\pi^++\pi^-$ $(\pi^-+\pi^0+\pi^0)$	(75.0) *(8)*	*(12)* (1.27×10^{-8}) *(2)*	(0)		(−)		$(-\frac{1}{2})$	(−1)
	θ^0			965 *(10)*	493 *(5)*	$\pi^++\pi^-$ $(\pi^0+\pi^0)$	214[o] *(5)*	*(4)* 1.3×10^{-10}[p] *(3)*	Int. ≠1		(+?)		$(-\frac{1}{2})$	(+1)

	Particle	Mass				Decay products	Q	Mean life	Spin	Magnetic moment	Parity	Isotopic spin		Gell-Mann's
	Symbol and charge	$(\frac{1}{16}O^{16})$[q]	(g)	(m_e)	(Mev)		(Mev)	(sec)	$(\hbar)$	$\left(\mu_{NM}=\frac{e\hbar}{2M_pc}\right)$		T	T_z	S
	(Atomic mass unit)	1.0000000			931.141[a] *(10)*									
Nucleons	p^+	1.0075964 *(15)*	1.67239×10^{-24} *(4)*	1836.12 *(2)*	938.214 *(10)*	stable		∞	$\frac{1}{2}$	+2.792743[r] *(3)*		$\frac{1}{2}$	$+\frac{1}{2}$	(0)
	n^0	1.0089861 *(15)*	1.67470×10^{-24} *(4)*	1838.65 *(2)*	939.508 *(10)*	$p^++e^-+\nu$	0.7830[q] *(9)*	1.11×10^3[s] *(22)* $(T_{\frac{1}{2}}=12.8$ min$)$	$\frac{1}{2}$	−1.913138[r] *(44)*		$\frac{1}{2}$	$-\frac{1}{2}$	(0)
	(H^1)	1.0081452 *(15)*												
Hyperons	Λ^0			2181.5 *(2)*	1114.7 *(1)*	$p^++\pi^-$ $(n^0+\pi^0)$	36.9[t] *(1)*	*(6)* 3.7×10^{-10}[u] *(5)*	$\frac{1}{2}$ Int.				(0)	(−1)
	Σ^+			2326.9 *(3)*	1189.0 *(1.5)*	$p^++\pi^0$ $n^0+\pi^+$	115.8[v,w] *(1)* 109.9 *(1)*	*(1.4)* $(\sim)3.4\times10^{-11}$[w,x] *(8)*	$\frac{1}{2}$ Int.				(+1)	(−1)
	Σ^-			(2326.9) *(3)*	(1189.0) *(1.5)*	$n^0+\pi^-$	(109.9) *(1)*	*(1.4)* $(\geqslant)3.4\times10^{-11}$ *(8)*	$\frac{1}{2}$ Int.				(−1)	(−1)
	Ξ^-			2586 *(7)*	1321 *(3.5)*	$\Lambda^0+\pi^-$	67[y] *(3)*	$\sim1\times10^{-10}$[x]	$\frac{1}{2}$ Int.				$(-\frac{1}{2})$	(−2)
	$(H^2)^+$	2.0141915 *(28)*	B.E. = −2.2264 Mev *(18)*		1875.496 *(14)*	stable		∞	1	+0.8574073[r] *(2)*	+	0	0	
	$(H^3)^+$	3.016456 *(5)*	B.E. = −8.458 Mev *(4)*		2808.746 *(17)*	$He_3^{++}+e^-+\nu$	0.0181[q] *(2)*	17.690 yr[z] *(6)*	$\frac{1}{2}$	+2.97884[r] *(1)*		$\frac{1}{2}$	$-\frac{1}{2}$	
	$(He^3)^{++}$	3.015888 *(5)*	B.E. = −7.720 Mev *(4)*		2808.217 *(17)*	stable		∞	$\frac{1}{2}$	−2.127544[r] *(7)*		$\frac{1}{2}$	$+\frac{1}{2}$	

II. Particles with properties not well determined.

Particle Symbol and charge (1)	Probable decay products (2)	Measured mass (m_e) (3)	Mean life (sec) (4)	If the mass were 966 m_e,					Obs. fraction of K^+ decays (10)
				Q (Mev) (5)	$E_{\text{chgd. sec.}}$ (Mev) (6)	$p_{\text{chgd. sec.}}$ (Mev/c) (7)	$p\beta_{\text{chgd. sec.}}$ (Mev/c) (8)	$R_{\text{chgd. sec.}}$ (g/cm^2 Pb) (9)	
$K_{\pi 2}^{(\pm)} \equiv \chi^{(\pm)}$ $(\equiv \theta^{(\pm)}?)$	$\pi^{(\pm)}+\pi^0$	964 ± 4*[aa] 967 ± 2†[bb] 968 ± 3*[cc] 964 ± 2*[bb] 966 ± 2 Av	$12.1^{+1.1}_{-1.0}\times10^{-9}$[ff] $\sim10\times10^{-9}$[aa]	219.1	108.5	205.1	169.6	60	~0.27
$K_{\pi 3}^{(\pm)} \equiv \tau'^{(\pm)}$ $(\equiv \tau^{(\pm)}?)$	$\pi^{(\pm)}+\pi^0+\pi^0$	968 ± 8‡[aa] 952 ± 16‡[dd] 965 ± 7 Av	$\sim10\times10^{-9}$[aa]	84.1	$\leqslant$ 53.1	$\leqslant$132.9	$\leqslant$ 91.6	$\leqslant$ 21.2	~0.02
$K_{\mu 2}^{(\pm)}$	$\mu^{(\pm)}+\nu$	964 ± 6*[aa] 976 ± 7*[cc] 965 ± 3*[bb] 968 ± 2†[bb] 966 ± 2 Av	$11.7^{+0.8}_{-0.7}\times10^{-9}$[ff] $\sim10\times10^{-9}$[aa]	388.0	152.5	235.5	214.9	106	~0.57
$K_{\mu 3}^{(\pm)} \equiv \kappa^{(\pm)}$	$\mu^{(\pm)}+\pi^0+\nu$ $(\mu^{(\pm)}+\gamma+\nu)$	$956\pm\ 9$‡[aa] 951 ± 15‡[dd] $967\pm\ 6$†[bb] $964\pm\ 5$ Av	$\sim10\times10^{-9}$[aa]	253.0	$\leqslant$134.0	$\leqslant$215.1	$\leqslant$193.1	$\leqslant$ 91	~0.04
$K_{e 3}^{(\pm)}$	$e^{(\pm)}+?+?$ $(e^{(\pm)}+\pi^0+\nu)$ $(e^{(\pm)}+\gamma+\nu)$	984 ± 25‡[aa] 988 ± 40[ee] 963 ± 10†[bb] $967\pm\ 9$ Av	$\sim10\times10^{-9}$[aa]						~0.04 The remaining fraction of the decays, ~0.06, are τ mesons.
p^-	Same mass as p^+ to within ±5%[gg]								

[a] Cohen, DuMond, Layton, and Rollett, Revs. Modern Phys. **27**, 363 (1955).
[b] L. M. Langer and R. J. D. Moffat, Phys. Rev. **88**, 689 (1952).
[c] Cowan, Reines, and Harrison, Phys. Rev. **96**, 1294 (1954).
[d] Koenig, Prodell, and Kusch, Phys. Rev. **88**, 191 (1952).
[e] Page, Stehle, and Gunst, Phys. Rev. **89**, 1273 (1953).
[f] M. Deutsch, Phys. Rev. **83**, 866 (1951).
[g] Smith, Birnbaum, and Barkas, Phys. Rev. **91**, 765 (1953); Barkas, Birnbaum, and Smith, Phys. Rev. **101**, 778 (1956).
[h] W. E. Bell and E. P. Hincks, Phys. Rev. **84**, 1243 (1951).
[i] Jakobson, Schultz, and Steinberger, Phys. Rev. **81**, 894 (1951); W. L. Kraushaar, Phys. Rev. **86**, 513 (1952).
[j] Durbin, Loar, and Havens, Phys. Rev. **88**, 179 (1952).
[k] W. Chinowsky and J. Steinberger, Phys. Rev. **93**, 586 (1954).
[l] D. H. Perkins, Phil. Mag. **46**, 1146 (1955); B. M. Anand, Proc. Roy. Soc. (London) **A220**, 183 (1953).
[m] E. Amaldi, "Report on τ-Mesons, Mimeographed Proceedings of the Pisa Conference on Elementary Particles, June, 1955," Nuovo cimento (to be published); H. H. Heckman, Nuovo cimento (to be published).
[n] L. Alvarez and S. Goldhaber, Nuovo cimento **2**, 344 (1955); Harris, Orear, and Taylor, Phys. Rev. **100**, 932 (1955); V. Fitch, New York Meeting of the American Physical Society, February 1, 1956 (unpublished).
[o] Thompson, Burwell, Cohn, Huggett, and Karzmark, Phys. Rev. **95**, 661 (1954).
[p] D. I. Page, Phil. Mag. **46**, 103 (1955); D. B. Gayther, Phil. Mag. **45**, 570 (1954); **46**, 1362 (1955).
[q] Li, Whaling, Fowler, and Lauritsen, Phys. Rev. **83**, 512 (1951); K. T. Bainbridge, *Experimental Nuclear Physics*, edited by E. Segrè (John Wiley and Sons, Inc., New York, 1953), Vol. I; R. W. King, Revs. Modern Phys. **26**, 327 (1954); D. M. van Patter and W. Whaling, Revs. Modern Phys. **26**, 402 (1954); Duckworth, Hogg, and Pennington, Revs. Modern Phys. **26**, 463 (1954); A. H. Wapstra, Physica **21**, 367 (1955).
[r] N. F. Ramsey, *Molecular Beams* (Oxford University Press, New York, 1956).
[s] J. M. Robson, Phys. Rev. **83**, 349 (1951).
[t] C. C. Butler, Report on Hyperons, Mimeographed Proceedings of the Pisa Conference on Elementary Particles, June, 1955.
[u] D. I. Page, Phil. Mag. **45**, 863 (1954).
[v] Friedlander, Keefe, and Menon, Nuovo cimento **1**, 482 (1955); Baldo, Belliboni, Ceccarelli, Grille, Sechi, Vitale, and Zorn, Nuovo cimento **1**, 1180 (1955).
[w] Schneps, Swami, Fry, and Snow, Bull. Am. Phys. Soc. Ser. II, **1**, 64 (1956).
[x] Davies, Evans, Fowler, Francois, Friedlander, Hiller, Iredale, Keefe, Menon, Perkins, and Powell, Mimeographed Proceedings of the Pisa Conference on Elementary Particles, June, 1955; Dahanayake, Francois, Fujimoto, Iredale, Waddington, and Yasin, Nuovo cimento **1**, 888 (1955).
[y] Castagnoli, Cortini, and Manfredini, Nuovo cimento **2**, 565 (1955).
[z] W. M. Jones, Phys. Rev. **100**, 124 (1955).

* Obtained from determination of the Q of the decay.
† Obtained from comparison of the K's range with that of protons of the same momentum.
‡ Obtained from comparison of the K's range with that of τ mesons of the same momentum, assuming 966 m_e for the mass of the τ.

[aa] Ritson, Pevsner, Fung, Widgoff, Zorn, Goldhaber, and Goldhaber, Phys. Rev. **101**, 1085 (1956).
[bb] Whitehead, Stork, Peterson, Perkins, and Birge, UCRL-3295 (March, 1956) (unpublished).
[cc] G-Stack Collaboration, Nuovo cimento **2**, 1063 (1955).
[dd] Heckman, Smith, and Barkas, UCRL-3156 (October, 1955) (unpublished); Nuovo cimento **3**, 85 (1956).
[ee] H. H. Heckman, UCRL-3003 (May, 1955) (unpublished).
[ff] V. Fitch and R. Motley, Phys. Rev. **101**, 496 (1956).
[gg] Chamberlain, Segrè, Wiegand, and Ypsilantis, Phys. Rev. **100**, 947 (1955).

by some cloud-chamber observations.[20,21,†] These observations suggest that, in addition to the production process

$$\pi^- + p \rightarrow \Lambda^0 + \theta^0,$$

there may also be a process

$$\pi^- + p \rightarrow \Sigma^0 + \theta^0,$$

where the Σ^0 decays very fast (mean life $\ll 10^{-10}$ sec) into a Λ^0 plus a photon.

There is no experimental evidence for a Ξ^0 hyperon, but its existence is also suggested by the "strange" particle schemes.[13,17]

3. Antineutron, and other Antiparticles

The production of antiprotons at Berkeley[22] suggests that antineutrons may also be produced. If the Dirac theory should be generally applicable, one may expect that every particle should have a corresponding antiparticle. The antiparticle should have all the same

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[20] Fowler, Shutt, Thorndike, and Whittemore, Phys. Rev. **98**, 121 (1955).
[21] W. D. Walker, Phys. Rev. **98**, 1407 (1955).
[22] Chamberlain, Segrè, Wiegand, and Ypsilantis, Phys. Rev. **100**, 947 (1955).

properties, except that the sign of the following properties should be reversed: the charge, the magnetic moment, the z component of the isotopic spin, the S value, and the baryon number M.[16]

4. Heavier Hyperons

Hyperons heavier than the Ξ^- may exist. Eisenberg[23] has observed an event which may be interpreted as evidence for such a particle. The suggested decay scheme for the observed event is

$$Y^- \rightarrow K^- + (n \text{ or } \Lambda^0) + (Q \cong 5 \text{ Mev}).$$

The sign of the particle was inferred from the fact that the stopping K meson was absorbed by a nucleus in the nuclear emulsion and produced a large star.

Fry, Schneps, and Swami[24] have also observed events which suggest the existence of heavier hyperons.

5. Other "Anomalous" Particles or Decay Modes

Other events have been observed which do not seem to fit the information compiled in the table and the preceding sections. It is not feasible to mention all of these, and thus only the most prominent phenomenon will be noted. This is the apparent existence of a group of negatively charged particles, believed to be mainly K particles, which have a considerably shorter mean life than the "normal" K particles.[25,†]

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Appendix added in proof.—The following comments are derived primarily from information presented at the Sixth Annual Rochester Conference (April, 1956). A full discussion of these points will be found in the proceedings of this conference, which are to be published. See also the Washington Meeting Bulletin of the American Physical Society (Series II, Vol. 1, April, 1956).

1. Among the negative K mesons, there is some evidence for the existence of $K_{\pi 2}^-$, K_{e3}^-, and possibly also $K_{\pi 3}^-$ and $K_{\mu 2}^-$ particles.
2. In addition to the π^0, Σ^+, and τ particles, it now appears necessary that the θ^0 and Λ^0 particles must have additional modes of decay, with only neutral secondaries being emitted. This is necessary if all "strange" particles (i.e., particles with $S \neq 0$) are made in "associated production"[16] and if no new strange particles are present.
3. Several experiments indicate that the Σ^- hyperon may be approximately 14 to 16 electron masses heavier than the Σ^+, and that the mean life of the Σ^- is $\sim 1.4 \times 10^{-10}$ sec, which is considerably greater than that of the Σ^+. This does not affect their both belonging to the same isotopic triplet family.
4. Several recent experiments on the lifetime of the θ^0 meson obtain lower values than that listed in the table. The new average value is approximately 1.0×10^{-10} sec.
5. The equality of the masses of the proton and antiproton has now been verified to within $\sim 2\%$.
6. Several events have been observed which indicate the probable existence of the following decay scheme:

$$K^0 \rightarrow e^\pm + \pi^\mp + (\text{a light neutral particle}).$$

7. Additional evidence for the existence of the Σ^0 hyperon has been obtained, and it appears quite probable that this particle does exist and does fit properly into the strange particle schemes.
8. It is now suggested that the group of negatively charged particles having a mean life of the order of 10^{-10} sec may be composed of Σ^- hyperons, rather than K^- mesons.

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[23] Y. Eisenberg, Phys. Rev. **96**, 541 (1954); Mimeographed Proceedings of the International Conference on Elementary Particles, Pisa, June, 1955 [Nuovo cimento (to be published)].

[24] Fry, Schneps, and Swami, Phys. Rev. **97**, 1189 (1955); Nuovo cimento **2**, 346 (1955).

[25] See, for example, reference 3, and G. H. Trilling and R. B. Leighton, Phys. Rev. **100**, 1468 (1955).