Tables of Elementary Particles and Resonant States

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INTRODUCTION

THOSE reported particles which are customarily called elementary are contained in Table I.

Table II is a catalog, possibly incomplete, of those reported particles which are customarily called resonances. Many of these resonant states have not been generally accepted. We leave it, however, to the user of the table to put question marks against or delete such resonances which do not agree with his theory or experiment.

CLASS, PARTICLE AND ANTIPARTICLE SYMBOLS

Division into hyperons, nucleons, and mesons is employed also for the resonances. The hyperonic states can then be logically defined as states with baryon number $B = 1$ and strangeness $S \neq 0$, the nucleonic states as states with $B = 1$ and $S = 0$, and the mesonic states as states with $B = 0$.

The leptons have been chosen so that μ^-, e^-, ν_μ, and ν_e are particles; μ^+, e^+, $\bar{\nu}_\mu$, and $\bar{\nu}_e$ antiparticles.

There are not yet name conventions for all resonances. For some of them many names are in use, out of which we have tried to choose the most convenient one. It is, for instance, not very practical to name the πN resonances N_1, N_2, N_3, and N_4 or N^*, N^{**}, N^{***}, and N^{****} now that a new πN resonance has been found which comes in between N_3 and N_4 (or N^{***} and N^{****}).

We expect the starred notation to become unpopular by the time a resonance is discovered which needs eight stars to fit into the system.

Some resonances have not yet been named. Without any intention of depriving the discoverers of their right in this respect, we herewith use some working names. The working names have been formed using the following rules:

1. A few letters are used for particular classes of resonances:
   - Ξ^* for $S = -2, B = 1$,
   - Y^* for $S = -1, B = 1$,
   - N^* for $S = 0, B = 1$ when they decay into π's and N,
   - Z^* for $S = 0, B = 1$ when they decay into strange particles,
   - K^* for $S = \pm 1, B = 0$,
   - κ for bosons which decay into $K\bar{K}$-pairs,
   - χ for bosons which decay into 4 pions,
   - ψ for $T = 2$ bosons which decay into 2 pions,
   - φ for $T = 0$ bosons which decay into 2 pions.
2. The baryons are given the two subscripts $2T$, $2J$ (for Ξ^*, N^* and Z^*) or T, $2J$ (for Y^*), and the strange bosons (K^*) one subscript, $2T$. Not known subscripts are left blank. Further degeneracy in the notation is resolved by adding more stars.
3. κ, χ, ψ and φ carry a subscript without physical significance, only to distinguish between different states.

Exceptions from rule 1 are ω_{ABC} (should be φ_0) and f^0 (should be φ_4 or ψ_6).

Clearly, symbols may change as further data become available or as other conventions are accepted.

In Table I particles and their found antiparticles are placed in separate columns. The only antiparticle not found (to our knowledge) is $\bar{\Xi}^0$. In Table II both particles and antiparticles are listed in the particle column.

QUANTUM NUMBERS

A blank space in any of the quantum-number columns may signify that the quantity in question is not known,* or that it cannot be defined (T, T_3, S, and parity for leptons). T is not repeated for isospin multiplets, nor is T, S, or parity repeated for antiparticles. In Table II, J, parity and G parity are not repeated for different charge states.

Different charge states are given separate entries when they have been found.

Parity is defined in relation to N and K; by definition, N has parity $+$ and K has $-$.

MASS AND MAGNETIC MOMENT

The mass is given in two units, MeV and $m_{\pi^\pm}$; for leptons $m_{\pi^\pm}$ is exchanged for m_e. We choose the units

$$\hbar = c = 1\,,$$

$$m_{\pi^\pm} = 139.58 \text{ MeV} = 2.4881 \times 10^{-25}\text{g}\,,$$

$$m_e = 0.510976 \text{ MeV}\,.$$

The accurate mass is expressed in MeV for all

* "Not known" here and henceforth is short for "not known to the compiler."

TABLE I. Elementary Particles, March 1963.

Class	Symbol Charge	Antiparticle found	Isospin T	Isospin T_3	Spin Parity	Strangeness	Mass (MeV)	Mass ($m_{\pi^\pm}$)	Magnetic moment ($e/2m_p$)	Mean life (sec)	Mean life ($1/m_{\pi^\pm}$)	Common decay modes	Branching ratios (%)	References
Hyperons	Ξ^-	$\overline{\Xi}^+$	$\frac{1}{2}$	$-\frac{1}{2}$ $\frac{1}{2}$	$\frac{1}{2}$	-2 2	1320.8 ± 0.4	9.46		$1.4\,(+0.6/-0.2) \times 10^{-10}$	3×10^{13}	$\Lambda\pi^-$	100	1
	Ξ^0			$\frac{1}{2}$		-2	1316	9.43		$3.9\,(+1.4/-0.9) \times 10^{-10}$	8×10^{13}	$\Lambda\pi^0$	100	2
	Σ^-	$\overline{\Sigma}^+$	1	-1 1	$\frac{1}{2}+$	-1 1	1195.96 ± 0.30	8.57		$(1.59 \pm 0.05) \times 10^{-10}$	3.4×10^{13}	$n\pi^-$	100	3, 4, 19
	Σ^0	$\overline{\Sigma}^0$		0 0	$\frac{1}{2}+$	-1 1	1191.5 ± 0.5	8.54		$10^{-11} > \tau > 10^{-22}$	$10^{12} > \tau > 10$	$\Lambda\gamma$	100	3, 5, 19
	Σ^+			1	$\frac{1}{2}+$	-1	1189.40 ± 0.20	8.52		$(0.78 \pm 0.03) \times 10^{-10}$	1.65×10^{13}	$p\pi^0$ $n\pi^+$	50.7 ± 2.3 49.3 ± 2.3	3, 4, 19
		$\overline{\Sigma}^-$		-1		1								
	Λ^0		0	0	$\frac{1}{2}+$	-1	1115.38 ± 0.10	7.991	-1.5 ± 0.5	$(2.57 \pm 0.30) \times 10^{-10}$	5.4×10^{13}	$p\pi^-$ $n\pi^0$	$66(+4/-3)$ $34(+3/-4)$	6, 20
		$\overline{\Lambda}^0$		0		1	1115.44 ± 0.32	7.991		$(1.9 \pm 1.0) \times 10^{-10}$	4×10^{13}			
Nucleons	n^0	$\overline{n}$	$\frac{1}{2}$	$-\frac{1}{2}$ $\frac{1}{2}$	$\frac{1}{2}+$	0 0	939.507 ± 0.01	6.731	-1.9128	1013 ± 26	2.15×10^{26}	$pe^-\bar{\nu}_e$	100	7, 8
	p^+			$\frac{1}{2}$	$\frac{1}{2}+$	0	938.213 ± 0.01	6.722	2.792816 ± 0.000034	∞	∞			7, 15
		$\overline{p}$		$-\frac{1}{2}$		0			-1.8 ± 1.2					10
Mesons	K^+		$\frac{1}{2}$	$\frac{1}{2}$	0^-	1	493.98 ± 0.14	3.539	0	$(1.227 \pm 0.008) \times 10^{-8}$	2.60×10^{15}	$\mu^+\nu_\mu(\mu 2)$ $\pi^+\pi^0(\pi 2)$ $\mu^+\pi^0\nu_\mu(\mu 3)$ $e^+\pi^0\nu_e(e3)$ $\pi^+\pi^+\pi^-(\tau^+)$ $\pi^+\pi^0\pi^0(\tau^{+\prime})$	64.2 ± 1.3 18.6 ± 0.9 4.8 ± 0.6 5.0 ± 0.5 5.7 ± 0.3 1.7 ± 0.2	9
	K^0	K^- $\overline{K}^0$		$-\frac{1}{2}$ $-\frac{1}{2}$ $\frac{1}{2}$	0^-	-1 1 -1	497.9 ± 0.6	3.57	<0.04 $\hbar e/m_K$	$K_1^0(0.90 \pm 0.02) \times 10^{-10}$ $K_2^0\ 6.3(+1.6/-1.0) \times 10^{-8}$	1.9×10^{13} 1.3×10^{16}	$\pi^+\pi^-$ $\pi^0\pi^0$ $\pi^+\pi^-\pi^0$ $3\pi^0$ $\pi^+e^-\bar{\nu}_e$, $\pi^-e^+\nu_e$ $\pi^+\mu^-\bar{\nu}_\mu$, $\pi^-\mu^+\nu_\mu$	69.4 ± 1.0 30.6 ± 1.0 8.7 ± 2.3 38 ± 7 28.3 ± 5.9 25.0 ± 5.9	11 12
	π^+	π^-	1	1 -1	0^-	0 0	139.58 ± 0.05	1	0	$(2.547 \pm 0.027) \times 10^{-8}$	5.48×10^{15}	$\mu^+\nu_\mu$	100	18
	π^0	π^0		0	0^-	0	134.97 ± 0.05	0.967	0	$(1.05 \pm 0.18) \times 10^{-16}$	2.23×10^{7}	2γ γe^+e^-	98.8 1.2	13, 22
Leptons	μ^-				$\frac{1}{2}$		105.65	206.765 ± 0.002 m_e	(1.001162 ± 0.000005) $e/2m_\mu$	$(2.210 \pm 0.002) \times 10^{-6}$	4.69×10^{17}	$e^-\bar{\nu}_e\nu_\mu$	100	14
		μ^+												
	e^-				$\frac{1}{2}$		0.510976 ± 0.000007	$1m_e$	$(1.0011609 \pm 0.0000024)$ $e/2m_e$	∞	∞			7, 15
		e^+												
	ν_μ^0	$\bar{\nu}_\mu$			$-\frac{1}{2}$ $+\frac{1}{2}$		< 2.5	$< 5m_e$						16, 21
	ν_e^0	$\bar{\nu}_e$			$-\frac{1}{2}$ $+\frac{1}{2}$		< 0.00025	$<5 \times 10^{-4}\, m_e$						17, 21
Photon	γ^0				1	0	0	0						21

particles, except the muon and the neutrinos, for which it is expressed in m_e. The mass in the other unit gives only the significant figures.

The magnetic moment is expressed in proton magnetons for baryons, in muon magnetons for the muon, and in electron magnetons for the electron.

The mass and magnetic moments of antiparticles are included when they have been specifically measured; otherwise, a blank space is left. A blank space in the magnetic-moment column may also indicate that the value is not known.

WIDTH AND LIFETIME

In Table I the mean life is given in two units, accurately in seconds and rounded off in $1/m_{\pi^\pm}$. The relation is

$$1/m_{\pi^\pm} = 4.7153 \times 10^{-24} \text{ sec},$$

the latter time signifying the time required for light to travel the distance of a Compton wavelength of the $\pi^\pm$ meson. This distance equals

$$1.4136 \times 10^{-13} \text{ cm}.$$

In Table II the full width Γ at half-maximum of the resonance is given in MeV, and the lifetime Γ^{-1} in units of $1/m_{\pi^\pm}$, to allow comparison with the mean lives in Table I.

A blank space means that the quantity is not known. Widths and lifetimes of antiparticles, and, in Table II, charge multiplets, are not included unless they have been specifically measured.

PRODUCTION PROPERTIES

In Table II one production reaction is given although others may also have been used. The laboratory momentum of the incident particle has been computed for that production reaction, at the threshold of resonance production.

A blank space in the k_{lab} column signifies that the rest masses in the production reaction have not been computed because no threshold exists or because it is questionable which threshold is of interest.

A blank space in both production columns indicates that detailed information on the production of different charge states is not available.

DECAY PROPERTIES

The most common decay modes are given if they have been observed. By "most common" we mean a branching ratio $\geqslant 1\%$.

The decay modes of antiparticles are not listed because they are simply the antimodes of the particles, and the branching ratios are the same. A blank space in any of the decay-property columns signifies that the information is lacking.

REFERENCES

All detailed information is collected in the reference list which does not claim to be complete. Use has been made of all literature available in Copenhagen by March 1963.

ACKNOWLEDGMENTS

Table I is the third version of a table prepared in 1958 by Dr. Monica Hessler and Dr. Bertel Laurent and revised in 1960 by the present compiler, all at the Institute for Theoretical Physics, Stockholm, at that time. The reason why the first-mentioned authors do not appear as co-authors in the present version is that they must not be held responsible for any erroneous or incomplete information contained in the present Table I, the inheritance of which is hereby gratefully acknowledged.

The present compiler is also indebted to Dr. Bertel Laurent, NORDITA, for helpful discussions, and to Dr. A. H. Rosenfeld in Berkeley, Dr. L. Bertanza in Pisa, Dr. G. von Dardel and Dr. L. di Lella of CERN, as well as to Dr. H. Pilkuhn, Stockholm, for fruitful correspondence. It is a pleasure to acknowledge the help given by my wife and by members of the NORDITA staff, as well as the financial support of NORDITA.

REFERENCES

1. m(Ξ^-) is a weighted average of the following results in MeV:

1320.4 ± 2.2, W. H. Barkas and A. H. Rosenfeld, University of California Radiation Laboratory Technical Report UCRL-8030 (unpublished), compilation of 12 Ξ^- found before March 1958.

1317.9 ± 1.9, W. B. Fowler, R. W. Birge, P. Eberhard, R. Ely, M. L. Good, W. M. Powell and H. K. Ticho, Phys. Rev. Letters **6**, 134 (1961).

1317.0 ± 2.2, V. A. Soloviev, *Proceedings of the 1960 Annual International Conference on High Energy Physics at Rochester* (University of Rochester, Rochester, 1960), p. 388.

1321.0 ± 0.5, L. Bertanza, V. Brisson, P. L. Connolly, E. L. Hart, I. S. Mittra, G. C. Moneti, R. R. Rau, N. P. Samios, I. O. Skillicorn, S. S. Yamamoto, M. Goldberg, L. Gray, J. Leitner, S. Lichtman, and J. Westgard, Phys. Rev. Letters **9**, 229 (1962).

1321.2 ± 2.4, a group from CERN, Ecole Polytechnique, and CEN, Saclay, Phys. Rev. Letters **8**, 257 (1962). A measurement of $\bar{\Xi}^+$.

1322.0 ± 1.3, H. N. Brown, B. B. Culwick, W. B. Fowler, M. Gailloud, T. E. Kalogeropoulos, J. K. Kopp, R. M. Lea, R. I. Louttit, T. W. Morris, R. P. Shutt, A. M. Thorndike, M. S. Webster, C. Baltay, E. C. Fowler, J. Sandweiss, J. R. Sanford, and H. D. Taft, Phys. Rev. Letters **8**, 255 (1962). A measurement of $\bar{\Xi}^+$.

$\tau(\Xi^-)$ is a central value of the following results in 10^{-10} sec:

1.28(+0.41/−0.25), Fowler, *et al.* (cf. above),

1.16(+0.26/−0.17), Bertanza, *et al.* (cf. above).

1.91 (+0.35/−0.25), L. Jauneau, D. Morellet, U. Nguyen-Khac, P. Petiau, A. Rousset, H. Bingham, D. C. Cundy, W. Koch, B. Ronne, H. Sletten, F. W. Bullock, A. K. Common, M. J. Esten, C. Henderson, F. R. Stannard, J. M. Scarr, J. Sparrow, A. G. Wilson, A. Halsteinslid, and R. Möllerud, Phys. Letters **4**, 49 (1963)

$J = 1/2$ is compatible with the data of Bertanza, *et al.*

2. $m(\Xi^0)$ is privately communicated by A. H. Rosenfeld, who refers to F. T. Solmitz' talk at Stanford American Physical Society meeting, Dec. 1962. $\tau(\Xi^0)$ is from Jauneau *et al.* (cf. reference 1).

3. The Σ mass has been taken from the compilation of W. H. Barkas and A. H. Rosenfeld, *Proceedings of the 1960 Annual International Conference on High Energy Physics at Rochester* (University of Rochester, Rochester, 1960), p. 877.

4. $\tau(\Sigma^+)$ and $\tau(\Sigma^-)$ are weighted averages of the following results in 10^{-10} sec:

$\tau(\Sigma^-) = 1.61^{+0.10}_{-0.09}$, $\tau(\Sigma^+) = 0.81^{+0.06}_{-0.05}$, Barkas and Rosenfeld compilation (cf. reference 3).

$\tau(\Sigma^-) = 1.58 \pm 0.06$, $\tau(\Sigma^+) = 0.765 \pm 0.04$, W. E. Humphrey and R. R. Ross, Phys. Rev. **127**, 1305 (1962).

The Σ^+ branching ratio for $p\pi^0$ decay is a weighted average of the following results: (51.0 ± 2.4)%, Humphrey and Ross; (48 ± 7)%, P. Granet, Compt. Rend. **255**, 282 (1962).

5. The upper limit of $\tau(\Sigma^0)$ is from L. W. Alvarez, H. Bradner, P. Falk-Variant, J. D. Gow, A. H. Rosenfeld, F. T. Solmitz, and R. Tripp, University of California Radiation Laboratory Technical Report UCRL-3775 (unpublished); the lower limit, from J. Dreitlein and B. W. Lee, Phys. Rev. **124**, 1274 (1961), who also give a theoretical estimate, $\tau(\Sigma^0) = 1.1 \times 10^{-19}$.

6. m(Λ) is a weighted average of the following results in MeV:

1115.36 ± 0.14, compilation of Barkas and Rosenfeld (cf. reference 3).

1115.46 ± 0.15, B. Bhowmik, D. P. Goyal and N. K. Yamdagni, Nuovo Cimento **22**, 296 (1961).

TABLE IIa. Baryonic Resonant States, March 1963.

Class	Symbol	Charge	Isospin	Spin	Parity	S	Mass (MeV)	Mass ($m_{\pi^\pm}$)	Full width Γ (MeV)	Life-time Γ^{-1} ($1/m_{\pi^\pm}$)	Production: Process	Production: k_{lab} (MeV)	Decay: Modes	Decay: Branching ratio (%)	Decay: Q (MeV)	References
Hyperonic States	Y^*_{05}	0	0	$\frac{5}{2}$ or $\frac{3}{2}$		−1	1815	13.0	120	1.16	K^-p	1050	K^-p others		383	23
	Y^{**}	0				−1	1770 ± 100	12.7			π^-p	2260	$Y^{*+}_{13}\pi^-$ $\Lambda\pi^+\pi^-$		245 376	55
	Y^*	0				−1	1715	12.2			π^-p	2185	K^0n	100	297	24
	Y^{**}_0	0	0			−1	1680	12.0	<20	>7	K^-p	760	$\Lambda\eta$		16	48
	Y^{**}_{13}	+	1	$\frac{3}{2}$		−1	1660 ± 10	11.9	40 ± 10	3.5	K^-p	715	$\bar{K}^0p$ $(\Sigma\pi)^+$ $\Lambda\pi^+$ $\Lambda\pi^+\pi^0$ $\Sigma^\mp\pi^\pm\pi^+$	~10 30 25 20 15	224 333 405 270 188	56
	Y^*_2		1 or 2			−1	1550 ± 20	11.1	125	1.75	π^-p	1770	$\Sigma\pi$	100	227–236	25
	Ξ^*_1	−	$\frac{1}{2}$	$\frac{3}{2}$	+	−2	1533 ± 3	10.98	≤7	≥20	K^-p	1512	$\Xi^-\pi^0$ $\Xi^0\pi^-$	40 60	78 82	26
	Ξ^*_1	0				−2						1521	$\Xi^-\pi^+$	100	73	26
	Y^*_{03}	0	0	$\frac{3}{2}$	−	−1	1520 ± 3	10.89	16	8.7	K^-p	395	$(\bar{K}N)^0$ $(\Sigma\pi)^0$ $\Lambda\pi^+\pi^-$	33 56 11	82–88 184–193 126	27
	Y^*_0	0	0			−1	1404.7 ± 0.4	10.1	<1.4	>100	K^-p	445	$(\Sigma\pi)^0$ $\Lambda\pi\pi$		69–78 10–20	28
	Y^*_{13}	−	1	$\frac{1}{2}$ or $\frac{3}{2}$	+	−1	1385 ± 5	9.92	50 ± 10	2.8	K^-p	408	$(\Sigma\pi)^-$ $\Lambda\pi^-$	1(±3) 99(±3)	54 130	29
	Y^*_{13}	0				−1						395	$(\Sigma\pi)^0$ $\Lambda\pi^0$		49–58 135	29
	Y^*_{13}	+				−1						408	$(\Sigma\pi)^+$ $\Lambda\pi^+$	1(±3) 99(±3)	53–61 130	29
Nucleonic States	N^*_3		$\frac{3}{2}$			0	2360 ± 25	16.9	200 ± 25	0.7	π^+p	2510	πN others		1280	60
	N^*_1		$\frac{1}{2}$			0	2190 ± 25	15.7	200 ± 20	0.7	π^-p	2080	πN others		1110	60
	Z^*_3	0	$\frac{3}{2}$	$\geqslant\frac{3}{2}$		0	1920 ± 20	13.8	15	9	$\pi^-(A)$		$K^0\Lambda$ $(K\Sigma)^0$		307 231	30 57
	N^*_{37}		$\frac{3}{2}$	$\frac{7}{2}$		0	1900	13.6	200	0.7	$\pi^-(A)$	1440	πN $K\Sigma$	30 <4	820 215	31
	N^*_{11}		$\frac{1}{2}$	$\frac{1}{2}$	+	0	1690	12.1			π^-p	1030	πN	100	612	32
	N^*_{15}		$\frac{1}{2}$	$\frac{5}{2}$	+	0	1683 ± 5	12.06	80	1.7	π^-p	1020	πN $K\Lambda$ others	80 <2 >18	605 74	31
	Z^*_1	0	$\frac{1}{2}$	$\geqslant\frac{1}{2}$		0	1650 ± 20	11.8	<7	>20	$\pi^-(A)$		$K^0\Lambda$	100	38	30
	N^*_{13}		$\frac{1}{2}$	$\frac{3}{2}$	−	0	1517 ± 3	10.87	60	2.3	π^-p	731	πN others		439	31
	N^*_{33}	−	$\frac{3}{2}$	$\frac{3}{2}$	+	0	1237	8.86	90 ± 20	1.6	πN	303	π^-n	100	158	31
	N^*_{33}	0				0							π^-p π^0n		159 163	31
	N^*_{33}	+				0							π^0p π^+n		164 158	31
	N^*_{33}	++				0							π^+p	100	159	31

1115.25 ± 0.36, R. Armenteros, E. Fett, B. French, L. Montanet, V. Nikitin, M. Szeptycka, Ch. Peyrou, R. Böck, A. Shapira, J. Badier, L. Blaskovicz, B. Equer, B. Gregory, F. Muller, S. J. Goldsack, D. H. Miller, C. C. Butler, B. Tallini, J. Kinson, L. Riddiford, A. Leveque, J. Meyer, A. Verglas, and S. Zylberach, *Proceedings of the 1962 Annual International Conference on High-Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962), p. 236.

1115.04 ± 0.41, C. Baltay, E. C. Fowler, J. Sandweiss, J. R. Sanford, H. D. Taft, B. B. Culwick, W. F. Fowler, J. K. Kopp, R. I. Louttit, R. P. Shutt, A. M. Thorndike, and M. S. Webster, *ibid.*, p. 233.

$\mu(\Lambda)$ is the value of R. L. Cool, E. W. Jenkins, T. F. Kycia, D. A. Hill, L. Marshall, and R. A. Schluter, Phys. Rev. **127**, 2223 (1962). A value of 0.0 ± 0.6 nucleon magnetons, given by W. Kernan, T. B. Novey, S. D. Warshaw, and A. Wattenburg, Phys. Rev. **129**, 870 (1963), has not been used.

$\tau(\Lambda)$ is a central value from the ideogram of F. S. Crawford, *Proceedings of the 1962 Annual International Conference on High-Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962), p. 827.

$m(\bar{\Lambda})$ is a weighted average of the following results in MeV:

1115.40 ± 0.39, Baltay *et al.* (cf. above).

1115.52 ± 0.55, Armenteros *et al.* (cf. above).

$\tau(\bar{\Lambda})$ is from Baltay *et al.*

The $\Lambda \rightarrow p\pi^-$ branching ratio is a central value of the following results in percent:

64.3 ± 1.6, Humphrey and Ross (cf. reference 4),

64.5 ± 2.2, weighted average based on earlier measurements, quoted by F. S. Crawford (cf. above),

68.5 ± 1.7, J. A. Anderson, F. S. and B. B. Crawford, R. L. Golden, L. J. Lloyd, G. W. Meisner and L. Price (to be published), quoted by F. S. Crawford (cf. above).

7. The nucleon and electron masses and the neutron magnetic moment are from compilations by Cohen, Crowe,

TABLE IIb. Mesonic Resonant States, March 1963.

Symbol	Charge	Isospin	Spin	Parity G-parity	S	Mass		Full width Γ (MeV)	Life-time Γ^{-1} $(1/m_{\pi^\pm})$	Production		Decay			References
						(MeV)	$(m_{\pi^\pm})$			Process	k_{lab} (MeV)	Modes	Branching ratio (%)	Q (MeV)	
K_3^*	$-$	$\geqslant \frac{3}{2}$			1	1630 ± 100	11.7			π^-p	3534	$(K_1^*\pi\pi)^-$		470	55
												$(K_1^*\rho)^-$		$\leqslant 100$	
												$(K\pi\rho)^-$		225	
												others			
K_3^*	$+$				1							same, charge +		same	55
χ_2	0				0	1340 ± 70	9.6			π^-p	2287	$(\rho\pi\pi)^0$		290	55
												others			
κ_3	0				0	1275 ± 25	9.1			π^-p	2125	$K^0\overline{K}^0$		279	24
												K^+K^-		287	
K^{**}					1	1260	9.0			π^-N		$K(n\pi)$			55
f	0	0	2	++	0	1253 ± 20	9.0	100 ± 50	1.4	π^-p	2070	$\pi^-\pi^+$	100	970	33
K_5^*	$--$	$\frac{5}{2}$			1	1150 ± 50	8.2			π^-p	2250	$K^0\pi^+\pi^+$		373	55
K_5^*	++				1							$K^0\pi^-\pi^-$		373	55
χ_1	$-$	1			0	1050	7.5			π^-p	1620	$\pi^-\pi^-\pi^+\pi^0$		496	51
χ_1	0				0	1040	7.4					$\pi^+\pi^-(\pi\pi)^0$		481–491	53
κ_2	0	0	even	++	0	1040 ± 40	7.4			K^-p	1780	$K_1^0K_1^0$		44	58
												even number π's			
κ_1	0	0	odd	$--$	0	1020	7.3	<3	>47	K^-p	1760	$K_1^0K_2^0$		24	59
												odd number π's			
ψ_5	$--$	2			0	990	7.2			π^-p	1490	$\pi^-\pi^-$	100	711	52
ψ_5	0				0							$\pi^-\pi^+$		711	52
ψ_5	++				0							$\pi^+\pi^+$	100	711	52
K_1^*	$-$	$\frac{1}{2}$	1	$-$	-1	888 ± 3	6.4	50 ± 10	2.8	K^-p	1074	$\overline{K}^0\pi^-$	60 ± 16	252	34
												$K^-\pi^0$	40 ± 16	261	
$\overline{K}_1^*$	0				-1					K^-p	1078	$K^-\pi^+$		256	34
												$\overline{K}^0\pi^0$		257	
K_1^*	+				1					π^-p	1834	$K^0\pi^+$	67	252	34
												$K^+\pi^0$	33	261	
K_1^*	0				1					π^-p	1657	$K^+\pi^-$		256	35, 34
												$K^0\pi^0$		257	
φ_3	0				0	885 ± 10	6.3			π^-p	1284	$\pi^+\pi^-$		606	36
ω	0	0	1	$--$	0	781.1 ± 0.8	5.6	<12	>12	$\overline{p}p$		$\frac{\text{neutr.}}{\pi^+\pi^-\pi^0}=$	0.12 ± 0.03	373	37
												$\pi^+\pi^-\gamma^0$	<2	503	
												$\pi^+\pi^-\pi^0\pi^0$	<12	232	53
												$\pi^+\pi^-\pi^+\pi^-$	<5	223	53
												$\pi^+\pi^-$	4	503	
ρ	$-$	1	1	$-$ +	0	757 ± 5	5.4	120 ± 10	1.2	π^-p	1029	$\pi^-\pi^0$	>91	475	38, 33, 39
												$\pi^-\pi^0\pi^0$	<3	340	53
												$\pi^-\pi^0\pi^0\pi^0$	≤ 4	205	54
												$\pi^-\pi^+\pi^-\pi^0$	<2	196	53
ρ	0				0	751 ± 6	5.4	110 ± 10	1.3	πN	1029	$\pi^-\pi^+$	94 (+6/−40)	470	40, 33, 36, 39
												neutrals	6 (+40/−6)		
												$\pi^+\pi^-\pi^+\pi^-$	<2	191	53
ρ_2	0				0	780	5.6	60	2.3	πN	1085	$\pi^-\pi^+$		500	41
												neutrals			
ρ_1	0				0	720	5.2	20	7	πN	975	$\pi^-\pi^+$		440	40
												neutrals			
ρ	+				0					π^+p	1066	$\pi^+\pi^0$		495	39
ψ_4	$--$	2			0	760	5.4			π^-p	1310	$\pi^-\pi^-$	100	481	52
ψ_4	0				0						1055	$\pi^-\pi^+$		481	52
ψ_4	++				0						1590	$\pi^+\pi^+$	100	481	52
K_1^{**}	0	$\frac{1}{2}$	$\geqslant 1$		1	730 ± 10	5.2	≤ 20	$\geqslant 7$	π^-p	1485	$K^+\pi^-$		96	50, 56
												$K^0\pi^0$		97	
K_1^{**}	+				1							$(K\pi)^+$		92–101	50, 56
δ	$-$	1 or 2			0	645 ± 25	4.5			π^-p	810	$\pi^-\pi^0$		350	43
δ	0				0							$\pi^+\pi^-$		345	43
δ	+				0							$\pi^+\pi^0$		350	43
α	0	1 or 2			0	625	4.5	<80	>1.7	pp		$\pi^+\pi^-\pi^0$		225	42
α	+				0							$\pi^+\pi^+\pi^-$		220	42
ψ_3	$--$	2	0 or 2		0	605 ± 25	4.3	75	1.9	π^-p	1025	$\pi^-\pi^-$	100	326	45, 52
ψ_3	0				0	580	4.2				733	$\pi^-\pi^+$		301	52
ψ_3	++				0						1235	$\pi^+\pi^+$	100	326	52, 45
ζ	$-$	1			0	564 ± 9	4.0	<43	>3.2	π^-p	707	$\pi^-\pi^0$		289	44
ζ	0				0	541 ± 18	3.9			π^-p	672	$\pi^+\pi^-$		262	44
ζ	+				0					π^+p		$\pi^+\pi^0$		289	44

TABLE IIb. Mesonic Resonant States, March 1963. (*Continued*)

Symbol	Charge	Isospin	Spin	Parity	G-parity	S	Mass (MeV)	Mass ($m_{\pi^\pm}$)	Full width Γ (MeV)	Life-time Γ^{-1} ($1/m_{\pi^\pm}$)	Production Process	Production k_{lab} (MeV)	Decay Modes	Decay Branching ratio (%)	Decay Q (MeV)	References
η	0	0	0	−	+	0	548.5 ± 0.6	3.93	≤ 7	⩾20	πp	685	$\pi^+\pi^-\pi^0$	25 ± 10	135	46
													$\pi^+\pi^-\gamma$	7 ± 2	270	
													$3\pi^0$		144	
													$\pi^0\gamma$	68 ± 10 (for $3\pi^0$, $\pi^0\gamma$, 2γ, others)	414	
													2γ		549	
													others			
φ_2	0	0				0	520 ± 20	3.7	70 ± 30	2.0	π^-p	639	$\pi^+\pi^-$		240	47
ψ_2	−−	2				0	440	3.1			π^-p	735	$\pi^-\pi^-$	100	160	52
ψ_2	0					0	420–440	3.1				515	$\pi^-\pi^+$		160	45, 52
ψ_2	++					0	440	3.1				975	$\pi^+\pi^+$	100	160	52
φ_1	0	0				0	395 ± 10	2.8	50 ± 20	2.8	π^-p	446	$\pi^+\pi^-$		115	47
ψ_1	−−	2				0	330	2.4			π^-p	557	$\pi^-\pi^-$	100	50	52
ψ_1	0					0	330	2.4				346	$\pi^-\pi^+$		50	52
ψ_1	++					0	330	2.4				790	$\pi^+\pi^+$	100	50	52
ω_{ABC}	0	0				0	317 ± 6	2.3	≤16	⩾9	pd		$\pi^+\pi^-$		38	49

and DuMond, Nuovo Cimento **5**, 541 (1957) and *Fundamental Constants of Physics* (Interscience Publishers, Inc., New York, 1957).

8. The neutron mean life is based on the value 11.7 ± 0.3 min for the half life, by A. N. Sosnovskij, P. E. Spivak, Y. A. Prokoviev, I. E. Kutikov, and Y. P. Dobrynin, Nucl. Phys. **10**, 395 (1959).

9. $m(K^+)$ is from the compilation of E. O. Okonov, Fortschr. Physik **8**, 42 (1960), who also gives the K^- mass as 493.9 ± 0.4 MeV.

$\tau(K^+)$ is a weighted average of the following results in 10^{-8}sec: 1.224 ± 0.013, compilation of Barkas & Rosenfeld (cf. reference 3), 1.231 ± 0.011, A. M. Boyarski, E. C. Loh, L. Q. Niemela, D. M. Ritson, R. Weinstein and S. Ozaki, Phys. Rev. **128**, 2398 (1962).

The K^+ branching ratios are from B. P. Roe, D. Sinclair, J. L. Brown, D. A. Glaser, J. A. Kadyk, and G. H. Trilling, Phys. Rev. Letters **7**, 346 (1961); and G. Giacomelli, D. Monti, G. Quareni, A. Quareni-Vignudelli, W. Püschel, and J. Tietge, Phys. Letters **3**, 346 (1963). Note that these branching ratios (except for τ) disagree with the weighted averages obtained from emulsion experiments, as quoted by Crawford (cf. reference 6):

$$\mu 2 = 57.4 \pm 2.0\,,$$
$$\pi 2 = 25.6 \pm 1.5\,,$$
$$\mu 3 + e3 + \tau = 11.0 \pm 1.0\,,$$
$$\tau = 5.7 \pm 0.2\,.$$

10. J. Button and B. C. Maglic, Phys. Rev. **127**, 1297 (1962).

11. $m(K^0)$ is from A. H. Rosenfeld, F. T. Solmitz and R. D. Tripp, Phys. Rev. Letters **2**, 110 (1959). $\mu(K^0)$ is from E. O. Okonov, J. Exptl. Theoret. Phys. (U.S.S.R.) **42**, 1554 (1962).

$\tau(K_1^0)$ is a weighted average, based on the following recent results only (in 10^{-10}sec), all quoted by Crawford (cf. reference 6):

0.94 ± 0.05, Crawford *et al.* (cf. below),

0.90 ± 0.05, A. F. Garfinkel, Report Nevis 104 (1962). [Thesis, Columbia University, Physics Department (unpublished).]

0.885 ± 0.025, R. L. Golden, G. Alexander, J. A. Anderson, F. S. and B. B. Crawford, L. J. Lloyd, G. W. Meisner, and L. Price (to be published).

The $K_1^0 \to \pi^0\pi^0$ branching ratio is a weighted average of the following results in percent:

28.5 ± 3.6 by F. S. Crawford, M. Cresti, R. Douglass, M. Good, G. Kalbfleisch, M. L. Stevenson, and H. Ticho, Phys. Rev. Letters **2**, 266 (1959),

29.4 ± 2.1, M. Chretien, V. Fisher, H. R. Crouch, R. E. Lanou, J. T. Massimo, A. M. Shapiro, J. P. Averell, A. E. Brenner, D. R. Firth, L. G. Hyman, M. E. Law, R. H. Milburn, E. E. Ronat, K. Strauch, J. C. Street, J. J. Szymanski, L. Guerriero, I. A. Pless, L. Roesenson, and G. A. Saladin (to be published), quoted by Crawford (cf. reference 6),

33.5 ± 1.4, J. L. Brown, J. A. Kadyk, G. H. Trilling, B. P. Roe, D. Sinclair, and J. C. Vander Welde, Phys. Rev. (to be published),

26.0 ± 2.4, Anderson *et al.* (cf. reference 6),

29 ± 3, weighted average of earlier results, reported at the 1960 Rochester Conference.

12. $\tau(K_2^0)$ is a weighted average of the following results in 10^{-8}sec

6.8 (+2.6/−1.5), Crawford (cf. reference 6),

8.1 (+3.3/−2.4), M. Bardon, K. Lande, L. M. Lederman, and W. Chinowsky, Ann. Phys. **5**, 156 (1958).

5.1 (+2.4/−1.3), S. E. Darmon, A. Rousset and W. Six, Phys. Letters **3**, 57 (1962).

The branching ratios have been obtained from the following results:

$R_1 = \dfrac{K_2^0 \to 3\pi^0}{K_2^0 \to \text{all charged}} = 0.38 \pm 0.07$, M. H. Anikina, M. S. Zhuravleva, D. M. Kotliarevsky, Z. S. Mandyavidze, A. M. Mestvirishvili, D. Neagu, E. O. Okonov, N. S. Petrov, A. M. Rosanova, V. A. Rusakov, G. G. Tachtamishev, and L. V. Chekhaidze, *Proceedings of the 1962 Annual International Conference on High-Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962), p. 452.

$R_2 = \dfrac{K_2^0 \to \pi^+\pi^-\pi^0}{K_2^0 \to \text{all charged}} = 0.127 \pm 0.020$, D. Luers, I. S. Mittra, W. J. Willis, and S. S. Yamamoto, *Proceedings of the Aix-en-Provence International Conference on Elementary Particles in 1961* (CEN Saclay, Seine et Oise, France, 1962), Vol. I, 241 (1961).

$R_2 = 0.134 \pm 0.018$, Anikina, *et al.*

$R_3 = \dfrac{K_2^0 \to \pi e \nu_e}{K_2^0 \to \text{all charged}} = 0.458 \pm 0.048$, Luers, *et al.*

$R_3 = 0.415 \pm 0.120$, A. Astier, L. Blaskovic, M. M. de Courreges, B. Equer, A. Lloret, P. Rivet, and J. Siaud, *Proceedings of the Aix-en-Provence International Conference on Elementary Particles in 1961* (CEN Saclay, Seine et Oise, France, 1962), Vol. I, 227 (1961). A value on $R_3 = (0.185^{+0.038}_{-0.034})$ by Astier *et al.* has not been used.

13. $\tau(\pi^0)$ is from G. von Dardel, D. Dekkers, R. Mermod, J. D. van Putten, M. Vivargent, G. Weber, and K. Winter, Phys. Letters **4**, 51 (1963).

The relative frequency for γe^+e^--decay is from J. Tietge and W. Püschel, Phys. Rev. **127**, 1324 (1962).

14. $\mu(\mu^+)$ is from G. Charpak, F. Farley, R. L. Garwin, T. Muller, J. C. Sens, and A. Zichichi, Phys. Letters **1**, 16 (1962).

$m(\mu^+)$ is a combined value of the latest measurements, as given by G. McD. Bingham, Nuovo Cimento **27**, 1352 (1963).

$\tau(\mu^+)$ is a weighted average from R. A. Lundy, Phys. Rev. **125**, 1686 (1962).

15. $\mu(e)$ and $\mu(p)$ are from A. A. Schupp, R. W. Pidd and H. R. Crane, Phys. Rev. **121**, 1 (1961).

16. J. Bahcall and R. B. Curtis, Nuovo Cimento **21**, 422 (1961).

17. L. M. Langer and R. J. D. Moffat, Phys. Rev. **88**, 689 (1952).

18. $m(\pi^{\pm})$ is from G. Shapiro and L. M. Lederman, Phys. Rev. **125**, 1022 (1962),

$\tau(\pi^{\pm})$ from A. W. Merrison, Advan. Phys. **11**, 41, 1 (1962).

19. The parity of Σ is $+$ from measurements of R. D. Tripp, M. B. Watson and M. Ferro-Luzzi, Phys. Rev. Letters **8**, 175 (1962), who conclude that $P(\Sigma pK) = -1$.

20. The Λ parity is $+$ from J. W. Cronin and O. E. Overseth, *Proceedings of the 1962 Annual International Conference on High Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962), p. 453, who give support for $P(K\Lambda) = -1$.

21. ν_μ and ν_e are left-handed screw states, $\bar{\nu}_\mu$ and $\bar{\nu}_e$ right-handed. γ has two spin states: right- and left-handed. We define a left- (right-)handed screw-state as a state with negative (positive) spin.

22. The π^0 mass has been obtained from the π^+ mass (cf. reference 18) and the measurement by J. B. Czirr, University of California Radiation Laboratory Technical Report UCRL-9951 (unpublished) and Bull. Am. Phys. Soc. **7**, 265 (1962) of the mass difference $m(\pi^-) - m(\pi^0) = (4.6064 \pm 0.0030)$ MeV.

23. L. T. Kerth, Rev. Mod. Phys. **3**, 389 (1961); O. Chamberlain, K. M. Crowe, D. Keefe, L. T. Kerth, A. Lemonick, Tin Maung, and T. F. Zipf, Phys. Rev. **125**, 1696 (1962). E. F. Beall, W. Holley, D. Keefe, L. T. Kerth, J. J. Thresher, C. L. Wang, and W. A. Wenzel, *Proceedings of the 1962 Annual International Conference on High Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962), p. 368; E. V. Kuznetsov and Ya. Ya. Shalamov, J. Exptl. Theoret. Phys. (U.S.S.R.) **43**, 1979 (1962).

24. V. V. Barmin, Y. S. Krestnikov, E. V. Kuznetsov, A. G. Meshkovsky, and V. A. Shebanov, J. Exptl. Theoret. Phys. (U.S.S.R.) **43**, 1564 (1962); March *et al.* (cf. reference 57); Kuznetsov *et al.* (cf. reference 23).

25. R. H. March, A. R. Erwin, and W. D. Walker, Phys. Letters **3**, 99 (1962);

W. Koch, J. D. Dowell, B. Leontic, A. Lundby, R. Meunier, J. P. Stroot, and M. Szeptycka, Phys. Letters **1**, 53 (1962);

D. Colley, N. Gelfand, U. Nauenberg, J. Steinberger, S. Wolf, H. R. Brugger, P. R. Kramer, and R. J. Plano, *Proceedings of the 1962 Annual International Conference on High Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962), p. 315 and Phys. Rev. **128**, 1930 (1962).

26. $m(\Xi_1^*)$ is a weighted average of the following results in MeV:

1529 ± 5, G. M. Pjerrou, D. J. Prowse, P. Schlein, W. E. Slater, D. H. Stork, and H. K. Ticho, Phys. Rev. Letters **9**, 114 (1962).

1535 ± 3, L. Bertanza, V. Brisson, P. L. Connolly, E. L. Hart, I. S. Mittra, G. C. Moneti, R. R. Rau, N. P. Samios, I. O. Skillicorn, S. S. Yamamoto, M. Goldberg, L. Gray, J. Leitner, S. Lichtman, and J. Westgard, Phys. Rev. Letters **9**, 180 (1962).

The spin and parity assignments are communicated privately by A. H. Rosenfeld.

27. M. Ferro-Luzzi, R. D. Tripp and M. B. Watson, Phys. Rev. Letters **8**, 28 (1962). Further evidence has been produced by G. Alexander, G. R. Kalbfleisch, D. H. Miller, and D. A. Smith, Phys. Rev. Letters **8**, 447 (1962); M. H. Alston, L. W. Alvarez, M. Ferro-Luzzi, A. H. Rosenfeld, H. K. Ticho, and S. G. Wojcicki, *Proceedings of the 1962 Annual International Conference on High Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962), p. 311; L. Bertanza, V. Brisson, P. L. Connolly, E. L. Hart, I. S. Mittra, G. C. Moneti, R. R. Rau, N. P. Samios, I. O. Skillicorn, S. S. Yamamoto, M. Goldberg, L. Gray, J. Leitner, S. Lichtman, and J. Westgard, *ibid.*, p. 279; Bastien *et al.* (cf. reference 56); March *et al.* (cf. reference 25); Alexander *et al.* (cf. reference 56).

28. $m(Y_0^*)$ and $\Gamma(Y_0^*)$ are from Å. Frisk and G. Ekspong, Phys. Letters **3**, 27 (1962). Further evidence: Y. Eisenberg, G. Yekutieli, P. Abrahamson, and D. Kessler, Nuovo Cimento **21**, 563 (1961); M. H. Alston, L. W. Alvarez, P. Eberhard, M. L. Good, W. Graziano, H. K. Ticho, and S. G. Wojcicki, Phys. Rev. Letters **6**, 698 (1961); P. Bastien, M. Ferro-Luzzi and A. H. Rosenfeld, Phys. Rev. Letters **6**, 702 (1961); Y. *International Conference on Elementary Particles in 1961* (CEN Saclay, Seine et Oise, France, 1962), p. 389; Wojcicki, University of California Radiation Laboratory Report UCRL-9835 (unpublished); Alston, *et al.* (cf. reference 27); Colley, *et al.* (cf. reference 25); Alexander, *et al.* (cf. reference 27 and 56); March *et al.* (cf. reference 57).

Note that all bubble chamber experiments are consistent with $\Gamma(Y_0^*) = 50$ MeV.

29. Review article by M. H. Alston and L. W. Ferro-Luzzi, Rev. Mod. Phys. **33**, 416 (1961); M. Taher-Zadeh, D. J. Prowse, D. H. Stork, and H. K. Ticho, Bull. Am. Phys. Soc. **6**, 510 (1961); M. M. Block, A. Engler, R. Gessaroli, J. Kopelman, M. Meer, A. Pevsner, P. Schlein, R. Strand, L. Grimellini, L. Lendinara, and L. Monari, Bull. Am. Phys. Soc. **7**, 49 (1962); A. R. Erwin, R. H. March and W. D. Walker, (cf. reference 25); Nuovo Cimento **24**, 237 (1962); Collaboration Saclay-Orsay-Bari-Bologne, *Proceedings of the Aix-en-Provence International Conference on Elementary Particles in 1961* (CEN Saclay, Seine et Oise, France, 1962), p. 375; Dowell *et al.* (cf. reference 25); Eisenberg and Kessler (cf. reference 28); J. Auman, M. M. Block, R. Gessaroli, J. Kopelman, S. Ratti, L. Grimellini, T. Kikuchi, L. Lendinara, L. Monari, and E. Harth, *Proceedings of the 1962 Annual International Conference on High Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962), p. 330; J. Button-Shafer, M. Ferro-Luzzi, J. Murray, M. L. Stevenson, and F. T. Solmitz, *ibid.*, pp. 303 and 307; C. T. Coffin, L. J. Curtis, D. I. Meyer, and K. M. Terwilliger, *ibid.*, p. 327; Alexander *et al.* (cf. reference 27 and 56); Colley *et al.* (cf. reference 25); Bertanza *et al.* (cf. reference 27); Bastien *et al.* (cf. reference 56).

The spin and parity assignments are from J. B. Shafer, J. J. Murray, and D. O. Huwe, Phys. Rev. Letters **10**, 179 (1963) and L. Bertanza, V. Brisson, P. L. Connolly, E. L. Hart, I. S. Mittra, G. C. Moneti, R. R. Rau, N. P. Samios, I. O. Skillicorn, S. S. Yamamoto, M. Goldberg, J. Leitner, S. Lichtman, and J. Westgard, Phys. Rev. Letters **10**, 176 (1963).

30. Z_3^* is reported by Erwin *et al.* (cf. reference 29); Z_1^* and Z_3^* by Y. V. Kuznetsov, Ya. Ya. Shalamov, A. F. Grashin, and Y. P. Kuznetsov, Phys. Letters **1**, 314 (1962), and Z_1^* by A. I. Baz, V. G. Vaks and A. I. Larkin, Nucl. Phys. **38**, 211 (1962), and L. Bertanza, P. L. Connolly, B. B. Culwick, F. R. Eisler, T. Morris, R. Palmer, A. Prodell, and A. Samios, Phys. Rev. Letters **8**, 332 (1962). No evidence for Z_1^* is found by Alexander *et al.* (cf. reference 56). Z_1^* may turn out to be identical with N_{15}^*.

(A) in the reaction column denotes heavy nuclei. The momenta were 1.89 GeV/c in the case of Erwin *et al.* (reference 29) and 2.8 GeV/c in the case of Kuznetsov *et al.* The spin and isospin assignments seem to have been deduced theoretically.

31. P. Falk-Vairant and G. Valladas, *Proceedings of the 1960 Annual International Conference on High Energy Physics at Rochester* (University of Rochester, Rochester, 1960) p. 38, and Rev. Mod. Phys. **33**, 362 (1961); B. J. Moyer, Rev. Mod. Phys. **33**, 367 (1961); J. C. Brisson, P. Falk-Vairant, J. P. Merlo, P. Sonderegger, R. Turlay, and G. Valladas, *Proceedings of the Aix-en-Provence International Conference on Elementary Particles in 1961*, (CEN Saclay, Seine et Oise, France, 1962), Vol. I, p. 45; J. F. Detoeuf, *ibid.*, II, p. 57; N. P. Samios, A. H. Bachman, R. M. Lea, T. E. Kalogeropoulos, and W. D. Shephard, Phys. Rev. Letters **9**, 139 (1962); E. L. Hart, R. I. Louttit, D. Luers, T. W. Morris, W. J. Willis, and S. S. Yamamoto, Phys. Rev. **126**, 747 (1962); Carmony *et al.* (cf. reference 37). According to J. A. Helland, T. J. Devlin, D. E. Hagge, M. J. Longo, B. J. Moyer and C. D. Wood, Bull. Am. Phys. Soc. **7**, 468 (1962) and Phys. Rev. Letters **10**, 27 (1963), there seems to be a superposition of $D_{5/2}$ and $F_{5/2}$ waves in the N_{15}^* peak and a $J = 7/2$ wave giving the largest contribution to the N_{37}^*, whereas no single state seems to give a dominant contribution to the N_{13}^* peak. Cf. also T. J. Devlin, B. J. Moyer and V. Perez-Mendez, Phys. Rev. **125**, 690 (1962). The N_{15}^* and N_{37}^* decay branching ratios are communicated privately by A. H. Rosenfeld.

32. B. T. Feld and W. M. Layson, *Proceedings of the Annual 1962 International Conference on High Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962) p. 147.

33. $m(f^0)$ is a weighted average of the following results in

MeV: 1260 ± 35, J. J. Veillet, J. Hennessy, H. Bingham, M. Block, D. Drijard, A. Lagarrigue, P. Mittner, A. Rousset, G. Bellini, M. di Corato, E. Fiorini, and P. Negri, Phys. Rev. Letters **10**, 29 (1963); 1250 ± 25, W. Selove, V. Hagopian, H. Brody, A. Baker, and E. Leboy, Phys. Rev. Letters **9**, 272 (1962). Evidence against f^0 has been given by C. Alff, D. Berley, D. Colley, N. Gelfand, U. Nauenberg, D. Miller, J. Schultz, J. Steinberger, T. H. Tan, H. Brugger, P. Kramer, and R. Plano, Phys. Rev. Letters **9**, 322 (1962).

34. $m(K_1^*)$ and $\Gamma(K_1^*)$ are "best values" from B. P. Gregory, *Proceedings of the 1962 Annual International Conference on High-Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962), p. 779. March *et al.* (cf. reference 25) give $\Gamma(K^*) - (35 \pm 15)$ MeV, in agreement with this. The spin and parity assignments are from W. Chinowsky, G. Goldhaber, S. Goldhaber, W. Lee, and T. O'Halloran, Phys. Rev. Letters **9**, 330 (1962).

The K_1^{*-} branching ratios are weighted averages of the following results:

$\Gamma(\overline{K}^0\pi^-)/\Gamma(K^-\pi^0) = 1.4 \pm 0.4$, M. Alston, L. W. Alvarez, P. Eberhard, M. L. Good, W. Graziano, H. K. Ticho, and S. G. Wojcicki, Phys. Rev. Letters **6**, 300 (1961).

$\Gamma(K^-\pi^0)/\Gamma(\overline{K}^0\pi^-) = 0.5 \pm 0.2$, W. Graziano and S. G. Wojcicki, Phys. Rev. **128**, 1868 (1962).

35. The π^- momentum for K_1^{*0} production is here tabulated as 1657 MeV/c, which corresponds to associated production with Λ. Associated production with Σ^0 gives 1826 MeV/c.

36. D. O. Caldwell, E. Bleuler, B. Elsner, L. W. Jones, and B. Zacharov, Phys. Letters **2**, 253 (1962). Evidence against the φ_3 has been given by Alff *et al.* (cf. reference 33). A $T = 2$ $\pi^-\pi^-\pi^0$ resonance at 870 MeV is indicated in the process $\pi^-n \rightarrow \pi^-\pi^-\pi^0p$ as reported by Shalamov *et al.* (cf. reference 51).

37. $m(\omega^0)$ is a weighted average of the following results in MeV:

782 ± 1, Alff *et al.* (cf. reference 33).

779.4 ± 1.4, R. Armenteros, R. Budde, L. Montanet, D. Morrison, S. Nilsson, A. Shapira, J. Vandermeulen, C. d'Andlau, A. Astier, C. Ghesquière, B. Gregory, D. Rahm, P. Rivet, and F. Solmitz, *Proceedings of the 1962 Annual International Conference on High Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962), p. 90.

The branching ratios are based on the upper limits given by G. R. Lynch, Proc. Phys. Soc. (London) **80**, 46 (1962) and by C. Alff, D. Berley, D. Colley, N. Gelfand, U. Nauenberg, D. Miller, J. Schultz, J. Steinberger, T. H. Tan, H. Brugger, P. Kramer, and R. Plano, Phys. Rev. Letters **9**, 325 (1962), and on the weighted average of the following results for ($\omega \rightarrow$ neutrals)/($\omega \rightarrow \pi^+\pi^-\pi^0$):

10 ± 4, Alff *et al.*

21 ± 7.5, Armenteros *et al.*

7 ± 6, M. Meer, R. Strand, R. Kraemer, L. Madansky, M. Nussbaum, A. Pevsner, C. Richardson, T. Toohig, M. Block, S. Orenstein, and T. Fields, *Proceedings of the 1962 Annual International Conference on High-Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962), p. 103.

25 ± 10, J. Button-Shafer, M. Ferro-Luzzi, J. Murray, M. L. Stevenson, and F. T. Solmitz, *ibid.*, p. 307.

By "neutrals" is primarily meant the $\pi^0\gamma$ channel. The $\pi^+\pi^-$ branching ratio is communicated privately by A. H. Rosenfeld.

$\Gamma(\omega^0)$ is consistent with zero in all measurements. The lowest upper limit is 12 MeV, as given by M. L. Stevenson, L. W. Alvarez, B. C. Maglić, and A. H. Rosenfeld, Phys. Rev. **125**, 687 (1962).

Further evidence has been given by B. C. Maglić, L. W. Alvarez, A. H. Rosenfeld, and M. L. Stevenson, Phys. Rev. Letters **7**, 178 (1961); N. H. Xuong and G. R. Lynch, Phys. Rev. Letters **7**, 327 (1961); Nuovo Cimento **25**, 923 (1962); Phys. Rev. **128**, 1849 (1962); A. Pevsner, R. Kraemer, M. Nussbaum, C. Richardson, P. Schlein, R. Strand, T. Toohig, M. Block, A. Engler, R. Gessaroli, and C. Meltzer, Phys. Rev. Letters **7**, 421 (1961); Hart *et al.* (cf. reference 31); W. D. Walker, E. West, A. R. Erwin, and R. H. March, *Proceedings of the 1962 Annual International Conference on High-Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962), p. 42; C. Richardson, R. Kraemer, M. Meer, M. Nussbaum, A. Pevsner, R. Strand, T. Toohig, and M. Block, *ibid.*, p. 96; T. Toohig, R. Kraemer, L. Madansky, M. Meer, M. Nussbaum, A. Pevsner, C. Richardson, R. Strand, and M. Block, *ibid.*, p. 99; T. Ferbel, J. Sandweiss, H. D. Taft, M. Gailloud, T. W. Morris, R. M. Lea, and T. E. Kalogeropoulos, *ibid.*, p. 76; D. D. Carmony, F. Grard, R. T. Van de Walle, and Nguyen-huu Xuong, *ibid.*, p. 44; G. B. Chadwick, W. Davies, M. Derrick, C. Hawkins, P. B. Jones, J. H. Mulvey, D. Radojicic, C. A. Wilkinson, M. Cresti, A. Grigoletto, S. Limentani, A. Loria, L. Peruzzo, and R. Santangelo, *ibid.*, p. 73.

38. $m(\rho^-)$ and $\Gamma(\rho^-)$ are weighted averages of the following results, tabulated as functions of the lab kinetic energy $T\pi$:

$m(\rho^\pm)$ (MeV)	$\Gamma(\rho^\pm)$ (MeV)	T_π (BeV)	References
713 ± 81	31 ± 143	0.91	Foelsche *et al.* (cf. reference 46)
748 ± 16		1.1	V. P. Kenney, W. D. Shephard and C. D. Gall, Phys. Rev. **126**, 736 (1962) and Nuovo Cimento **23**, 245 (1962)
755 ± 10	61 ± 24	1.26	Foelsche *et al.* (cf. reference 46)
752 ± 13		1.45	Saclay - Orsay - Bari - Bologna-collaboration, Aix[a], p. 257 and Nuovo Cimento (to be published)
740 (±13)	120 (±15)	1.72–1.93	Walker *et al.* (cf. reference 37)
770 ± 10	130 ± 10	2.19–2.73	Alff *et al.* (cf. reference 33)
780 (±25)		7.0	A. F. Grashin and Ya. Ya. Shalamov, CERN[b], p. 58
755 (±15)	110 (±15)	$\overline{p}p$ at rest	G. B. Chadwick, W. T. Davies, M. Derrick, C. Hawkins, J. H. Mulvey, D. Radojicic, C. A. Wilkinson, M. Cresti, S. Limentani, and R. Santangelo, CERN[b], p. 69 and Phys. Rev. Letters **10**, 62 (1963)

[a] *Proceedings of the Aix-en-Provence International Conference on Elementary Particles in 1961* (CEN Saclay, Seine et Oise, France, 1962), Vol. I, (1961).
[b] *Proceedings of the Annual 1962 International Conference on High-Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962).

The above mass values are all consistent with 757 ± 5, and no evidence for an energy dependence can be seen. In fact, the only such evidence has been presented by Foelsche *et al.*, who give $m(\rho^+) = 726 \pm 10$ and $\Gamma(\rho^+) = 57 \pm 27$ at $T\pi = 1.09$ BeV. This value has not been used by us.

Further evidence on ρ^- has been given by M. S. Aĭnutdinov, S. Ya. Nikitin, Ya. M. Selector, A. F. Grashin and S. M. Zombkovskii, *Proceedings of the 1962 Annual International Conference on High Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962), p. 61 and Soviet Phys.–JETP **15**, 979 (1962); A. F. Grashin and Ya. Ya. Shalamov, Soviet Phys.–JETP **15**, 770 and 787 (1962); W. D. Shephard and W. D. Walker, Phys. Rev. **126**, 278 (1962); J. Derrick, quoted by Lynch, Proc. Phys. Soc. (London) **80**, 46 (1962); E. West, J. Bishop, J. Boyd, A. R. Erwin, D. Lyon, R. H. March, P. H. Satterblom, and D. H. Walker, Bull. Am. Phys. Soc. **7**, 281 (1962); Z. G. T. Guiragossian, W. M. Powell and H. S. White, Bull. Am. Phys. Soc. **7**, 281 (1962); Grote, Klabuhn, Klugow, Krecker, Kundt, Lanius, and Meier, Nucl. Phys. **34**, 648 and 659 (1962).

39. Further evidence on ρ has been given by J. A. Anderson, V. X. Bang, P. G. Burke, D. D. Carmony, and N. Schmitz, Phys. Rev. Letters **6**, 365 (1961); A. H. Rosenfeld, D. D.

Carmony and R. T. Van de Walle, Phys. Rev. Letters **8**, 293 (1962); E. M. Friedlander, Phys. Rev. **127**, 247 (1962).

40. $m(\rho^0)$ and $\Gamma(\rho^0)$ are weighted averages of the following results, tabulated as functions of the lab kinetic energy T_π:

$m(\rho^0)$ (MeV)	$\Gamma(\rho^0)$ (MeV)	T_π (BeV)	References
752 ± 27		1.45	Saclay-Orsay-Bari-Bologna Collaboration, Nuovo Cimento (to be published)
760 (±15)		1.72	Walker *et al.* (cf. reference 37)
750 ± 10	100 ± 10	2.19–2.73	Alff *et al.* (cf. reference 33)
742 (±15)		2.64	Grashin *et al.* (cf. reference 38)
747 ± 17	156 ± 17	4.55	Samios *et al.* (cf. reference 31)
750 (±15)		7.0	Grote *et al.* (cf. reference 38)
755 (±15)	110 (±15)	$\bar{p}p$ at rest	Kenney *et al.* (cf. reference 38)

There is no evidence for an energy dependence.

The branching ratios are from Meer *et al.* (cf. reference 37).

Further evidence on ρ^0 has been given by Maglić *et al.* (cf. reference 37); Guiragossian *et al.* (cf. reference 38); W. B. Johnson, L. B. Auerbach, T. Ypsilantis, C. E. Wiegand, J. Lach. and T. Elioff, Phys. Rev. Letters **9**, 173 (1962); Shephard and Walker (cf. reference 38).

41. $m(\rho_1^0)$, $m(\rho_2^0)$, $\Gamma(\rho_1^0)$, and $\Gamma(\rho_2^0)$ are from J. Button, G. R. Kalbfleisch, G. R. Lynch, B. C. Maglić, A. H. Rosenfeld, and M. L. Stevenson, Phys. Rev. **126**, 1858 (1962). Further evidence on ρ_1^0 and ρ_2^0 has been given by Walker *et al.* (cf. reference 37).

42. $m(\alpha)$ is given by E. Pickup, D. K. Robinson and E. O. Salant for α^0 and α^+ in Phys. Rev. Letters **8**, 329 (1962). An indication for $m(\alpha^+) = 655$ MeV is given by B. Sechi Zorn in Phys. Rev. Letters **8**, 282 (1962). Evidence against α has been given by Alff *et al.* (cf. reference 33). Indication for a $T = 2$ $(\pi^-\pi^-\pi^0)$ resonance at 630 MeV has been reported by Shalamov *et al.* (cf. reference 51).

43. M. Roos, Phys. Letters **3**, 242 (1963).

44. $m(\zeta^-)$ is the weighted average given by Roos (cf. reference 43), where however the new values (590 ± 20) MeV of R. Barloutaud, J. Heughebaert, A. Leveque, C. Louedec, J. Meyer, and D. Tycho, Nuovo Cimento **27**, 238 (1963), and (541 ± 18) MeV of the Saclay-Orsay-Bari-Bologna Collaboration, Nuovo Cimento (to be published), have been included. The last mentioned value is also used for $m(\zeta^0)$. The isospin assignment is from B. Sechi Zorn, Phys. Rev. Letters **8**, 282 (1962).

Evidence against the existence of the ζ has been given by Alff *et al.* (cf. reference 33), Chadwick *et al.* (cf. reference 37); D. Stonehill, C. Baltay, H. Courant, W. Fickinger, E. C. Fowler, H. Kraybill, J. Sandweiss, J. Sanford and H. Taft, Phys. Rev. Letters **6**, 624 (1961). Selove *et al.* (cf. reference 33), Caldwell *et al.* (cf. reference 36), Samios *et al.* (cf. reference 31), Johnson *et al.* (cf. reference 40); R. R. Crittenden, B. Musgrave and H. J. Martin, Bull. Am. Phys. Soc. **7**, 468 (1962); J. Kirz, J. Schwartz, and R. D. Tripp, UCRL-10676 and Phys. Rev. (to be published).

45. N. N. Biswas, I. Derado, K. Gottstein, V. P. Kenney, D. Luers, G. Lutjens, and N. Schmitz, Phys. Letters **3**, 11 (1962); M. C. Foster, M. L. Good, R. P. Matsen, M. W. Peters, G. W. Tautfest, and R. B. Willmann, *Proceedings of the 1962 Annual International Conference on High-Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962), p. 108; Richardson *et al.* (cf. reference 37); Shalamov *et al.* (cf. reference 51); S. F. Tuan, Nuovo Cimento **23**, 448 (1962). Evidence against the ψ_2^0 and the ψ_3^0 has been given by Alff *et al.* (cf. reference 33).

46. $m(\eta^0)$ is a weighted average of the following results in MeV:

548 ± 1, Alff *et al.* (cf. reference 33);

548 ± 1, H. Foelsche, E. C. Fowler, H. L. Kraybill, J. R. Sanford, and D. Stonehill, Phys. Rev. Letters **9**, 223 (1962), at 1090 MeV/c;

551 ± 2, Foelsche *et al.*, at 1260 MeV/c;

546 ± 4, Pickup *et al.* (cf. reference 42);

550 ± 1.5, 548 ± 2 } P. L. Bastien, J. P. Berge, O. I. Dahl, M. Ferro-Luzzi, D. H. Miller, J. J. Murray, A. H. Rosenfeld, and M. B. Watson, Phys. Rev. Letters **8**, 114 (1962), from different decay modes.

$\Gamma(\eta^0)$ is from Bastien *et al.* Alff *et al.* and Foelsche *et al.* give $\Gamma < 10$ MeV.

The isospin assignment is from D. D. Carmony, A. H. Rosenfeld and R. T. Van de Walle, Phys. Rev. Letters **8**, 117 (1962), and the spin and parities from M. Chrétien, F. Bulos, H. R. Crouch, Jr., R. E. Lanou, J. T. Massimo, A. M. Shapiro, J. A. Averell, C. A. Bordner, Jr., A. E. Brenner, D. R. Firth, M. E. Law, E. E. Ronat, K. Strauch, J. C. Street, J. J. Szymanski, A. Weinberg, B. Nelson, I. A. Pless, L. Rosenson, G. A. Salandin, R. K. Yamamoto, L. Guerriero, and F. Waldner, Phys. Rev. Letters **9**, 127 (1962).

The branching ratios have been computed from the following measurements:

$R_1 = \dfrac{\pi^+\pi^-\gamma}{\pi^+\pi^-\pi^0} = 0.26 \pm 0.08$, E. C. Fowler, F. S. Crawford, L. J. Lloyd, R. A. Grossman, L. Price, Phys. Rev. Letters **10**, 110 (1963).

$R_2 = \dfrac{\text{neutrals}}{\pi^+\pi^-\pi^0} = 2.5 \pm 0.5$, Alff *et al.*

$R_2 = 2.5 \pm 1.0$, Pickup *et al.*

$1/R_2 = 0.31 \pm 0.11$, Bastien *et al.*

$R_2/(1 + R_1) = 2.7 \pm 0.8$, Button-Shafer *et al.* (cf. reference 29).

$R_2/(1 + R_1) = 3.1 \pm 1.2$, Meer *et al.* (cf. reference 37).

Chrétien *et al.* also give the branching ratio $R_3 = \dfrac{3\pi^0}{2\gamma} \leq 1.1 \pm 0.3$.

Further evidence on η has been given by Pevsner *et al.* (cf. reference 37); Foster *et al.* (cf. reference 45); C. Mencuccini, R. Querzoli, G. Salvini, and V. G. Silvestrini, *Proceedings of the 1962 Annual International Conference on High-Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962), p. 33; H. Foelsche, E. C. Fowler, H. L. Kraybill, J. R. Sanford, and D. Stonehill, the same conference, p. 36; W. D. Walker, J. Boyd, A. R. Erwin, H. R. Fechter, D. Lyon, R. H. March, P. H. Satterblom, and E. West, Bull. Am. Phys. Soc. **7**, 281 (1962).

47. Samios *et al.* (cf. reference 31). Evidence for φ_1 has been reported by J. Schwartz, J. Kirz, and R. Tripp, Bull. Am. Phys. Soc. **7**, 282 (1962) and UCRL-10676 (to be published in the Phys. Rev.), and by T. D. Blokhintseva, V. G. Grebinnik, V. A. Shukov, G. Liebman, L. Nemenov, G. I. Selivanov, and Yuang Shunfan, Joint Institute of Nuclear Research technical report P-1056 (Dubna 1962).

Evidence against the φ_1 and the φ_2 has been given by Alff *et al.* (cf. reference 33).

48. B. L. Ioffe, J. Exptl. Theoret. Phys. (U.S.S.R.) **43**, 341 (1962).

49. $m(\omega_{ABC})$ is a weighted average of the following results in MeV:

310 ± 10, A. Abashian, N. E. Booth and K. M. Crowe, Phys. Rev. Letters **5**, 258 (1960), **7**, 35 (1961) and Rev. Mod. Phys. **33**, 393 (1961).

322 ± 8, B. Richter, Phys. Rev. Letters **9**, 217 (1962).

Further evidence has been given by Button *et al.* (cf. reference 40). No evidence has been found by L. Lapidus, *Proceedings of the 1962 Annual International Conference on High-Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962), p. 115 nor by Kirz *et al.* (cf. reference 44) nor by Blokhintseva *et al.* (cf. reference 47).

50. G. Alexander *et al.* (cf. reference 27). No evidence for the K_1^{**} has been found by Colley *et al.* (cf. reference 25).

51. W. D. Walker, J. Boyd, A. R. Erwin, H. R. Fechter, D. Lyon, R. H. March, P. H. Satterblom, and E. West, Bull. Am. Phys. Soc. **7**, 281 (1962). Indication for a $T = 2(\pi^-\pi^-\pi^0)$ resonance at 1050 MeV in the process $\pi^- n \rightarrow \pi^-\pi^-\pi^0$ has been reported by Ya. Ya. Shalamov and A. F. Grashin, J. Exptl. Theoret. Phys. (U.S.S.R.) **44**, 65 (1963).

52. Guiragossian *et al.* (cf. reference 38); M. S. Ainutdinov, S. M. Zombkovskii, Y. M. Selector, S. Y. Nikitin, and V. N. Shuylachenko, J. Exptl. Theoret. Phys. (U.S.S.R.) **43**, 1543 (1962).

53. Nguyen-Huu Xuong and G. R. Lynch, Nuovo Cimento **25**, 923 (1962) and Phys. Rev. **128**, 1849 (1962); Chadwick; *et al.* (cf. reference 37); Foelsche *et al.* (cf. reference 46). G. R. Lynch, Proc. Phys. Soc. (London) **80**, 46 (1962).

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56. P. L. Bastien, J. P. Berge, O. I. Dahl, M. Ferro-Luzzi, J. Kirz, D. H. Miller, J. J. Murray, A. H. Rosenfeld, R. D. Tripp, and B. Watson, *Proceedings of the 1962 Annual International Conference on High-Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962), p. 373; W. A. Cooper, H. Courant, H. Filthuth, E. I. Malamud, A. Minguzzi-Ranzi, H. Schneider, A. M. Segar, G. A. Snow, W. Willis, E. S. Gelsema, J. C. Kluyver, A. G. Tenner, K. Browning, I. S. Hughes, and R. Turnbull, *ibid.*, p. 298; G. Alexander, L. Jacobs, G. R. Kalbfleisch, D. H. Miller, G. A. Smith, and J. Schwartz, *ibid.*, p. 320; Alston *et al.* (cf. reference 27); Kuznetsov *et al.* (cf. reference 21). P. L. Bastien and J. P. Berge, Phys. Rev. Letters **10**, 188 (1963); L. W. Alvarez, M. H. Alston, M. Ferro-Luzzi, D. O. Huwe, G. R. Kalbfleisch, D. H. Miller, J. J. Murray, A. H. Rosenfeld, J. B. Shafer, F. T. Solmitz, and S. G. Wojcicki, Phys. Rev. Letters **10**, 184 (1963); A. H. Rosenfeld (private communication).

57. March *et al.* (cf. reference 25); W. D. Walker, *Proceedings of the 1962 Annual International Conference on High-Energy Physics at Geneva* (CERN, Geneva, Switzerland, 1962), p. 335. The Z_3^* and the N_{37}^* are probably identical. At present only the very different lifetimes make them look different.

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59. Bertanza *et al.* (cf. reference 26); A. H. Rosenfeld (private communication).

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