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The mass of the $\psi(3095)$ as an $N\bar{N}$ resonance

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Guided by a suggestion that the $\psi(3095)$ is an $N\bar{N}$ resonance, and using the basis states of a previously published light-quark model, we "calculate" the mass of the ψ as 3105^{+5}_{-15} MeV. The appearance of a narrow-width meson resonance at this mass value is consistent with a systematic formalism that was devised to generate the observed spectrum of lower-mass narrow-width meson resonances. However, the width of the ψ is narrower by a factor of $\alpha^{-1}=137$ than we would have anticipated on the basis of the light-quark model. The $\psi'(3684)$ resonance also fits into this formalism, but the mass of the ψ' has a larger calculational uncertainty since it is above the $N\bar{N}N\bar{N}$ threshold.

In Refs. 1 and 2 a light-quark model was defined which reproduces, among other things, the spectrum of narrow-width meson resonances. This light-quark model includes both a set of light-quark basis states and an excitation formalism[3] for mapping the observed narrow-width meson resonances. By extending the excitation formalism along lines indicated in Ref. 1, we accurately reproduce the mass of the $\psi(3095)$, and we approximately reproduce the mass of the $\psi'(3684)$.

Figure 1 of this paper is Fig. 8 of Ref. 1, and it is a mapping of all of the observed narrow-width and S-state meson and baryon resonances in the form of "excitation towers" built on a set of fundamental hadron "ground states." Guided by a recent paper of Goldhaber and Goldhaber,[4] we have assigned the $\psi(3095)$ resonance[5] to the $N\bar{N}$ excitation tower in Fig. 1 which contains the $\bar{p}n(1795)$ (Ref. 6) and $\bar{p}p(1925)$ (Ref. 7) resonances. The $\psi'(3684)$ resonance[5] also appears to belong to this same excitation tower.

In the context of this light-quark model,[1,2] with quarks having very small binding energies (a few percent), the observed spectrum of narrow-width meson resonances is accurately reproduced[3] by adding together combinations of light-quark basis states which have either ~4% or ~0% binding energies, depending on the strangeness characteristics of the basis states.[8] In the case of the $\psi(3095)$ meson the ~0%-binding-energy rule applies, since the nonstrange $\bar{p}n(1795)$ "ground state" combines with a nonstrange "excitation quantum." In Fig. 1 [which was originally published prior to the appearance of the $\psi(3095)$ resonance], the nonstrange resonance denoted as $K_SK_S(1311)$ has an experimental mass of about 1310 ± 3 MeV.[9] Thus, if we combine this mass as an excitation quantum with the $\bar{p}n$ ground-state mass of 1794.5 ± 1.4 MeV,[6] using the ~0%-binding-energy rule, we obtain a narrow meson resonance with a "calculated" mass of 3104.5 ± 4 MeV. If we now allow for the fact that in some resonances [notably the $\omega(784)$ (see Ref. 1)] the ~0%-binding-energy approximation actually corresponds to a binding energy of about 10 MeV, and if we allow for small electromagnetic corrections to the binding energy,[2] we arrive at a final "calculated" mass for the ψ of 3105^{+5}_{-15} MeV. This compares with the experimental ψ mass of 3095 ± 4 MeV.[5]

This addition of two resonances to form another resonance is not as arbitrary as it might seem from the present discussion. It follows, in fact, from an excitation formalism[3] that was devised specifically to reproduce the observed spectrum of lower-mass narrow-width meson resonances. In the notation of Ref. 1, the ψ is a ${}^5E_{33333}$ excitation,[3] and it belongs to the group of "triplet excitations" (Table XXII of Ref. 1) which are expected to dominate the high-mass portion of the meson spectrum. The $\psi'(3684)$ also fits into this same excitation sequence; it is a ${}^6E_{333333}$ excitation. If we assign the ψ' to the $N\bar{N}(1795)$ excitation tower in Fig. 1 that also contains the ψ (an assignment which is suggested by the dominant $\psi'\to\psi\pi\pi$ decay mode), then the "excitation quantum" for the ψ' must be about $3684-1795=1889$ MeV, which is above the $N\bar{N}$ bound-state threshold. Since the $N\bar{N}$ bound-state resonance has a 4% binding energy,[6] this means that the ψ' excitation quantum can be some (unknown) mixture of ~4% and ~0% binding energies. We can write

$$N\bar{N}+N\bar{N}\approx 3590 \text{ MeV (~4\% binding energy)}$$

and

$$N\bar{N}+1310 \text{ MeV}+655 \text{ MeV}=3760 \text{ MeV} \quad \text{(~0\% binding energy)}$$

as two limits on the calculated ψ' mass; these limits bracket the observed[5] 3684-MeV mass of the ψ' resonance.

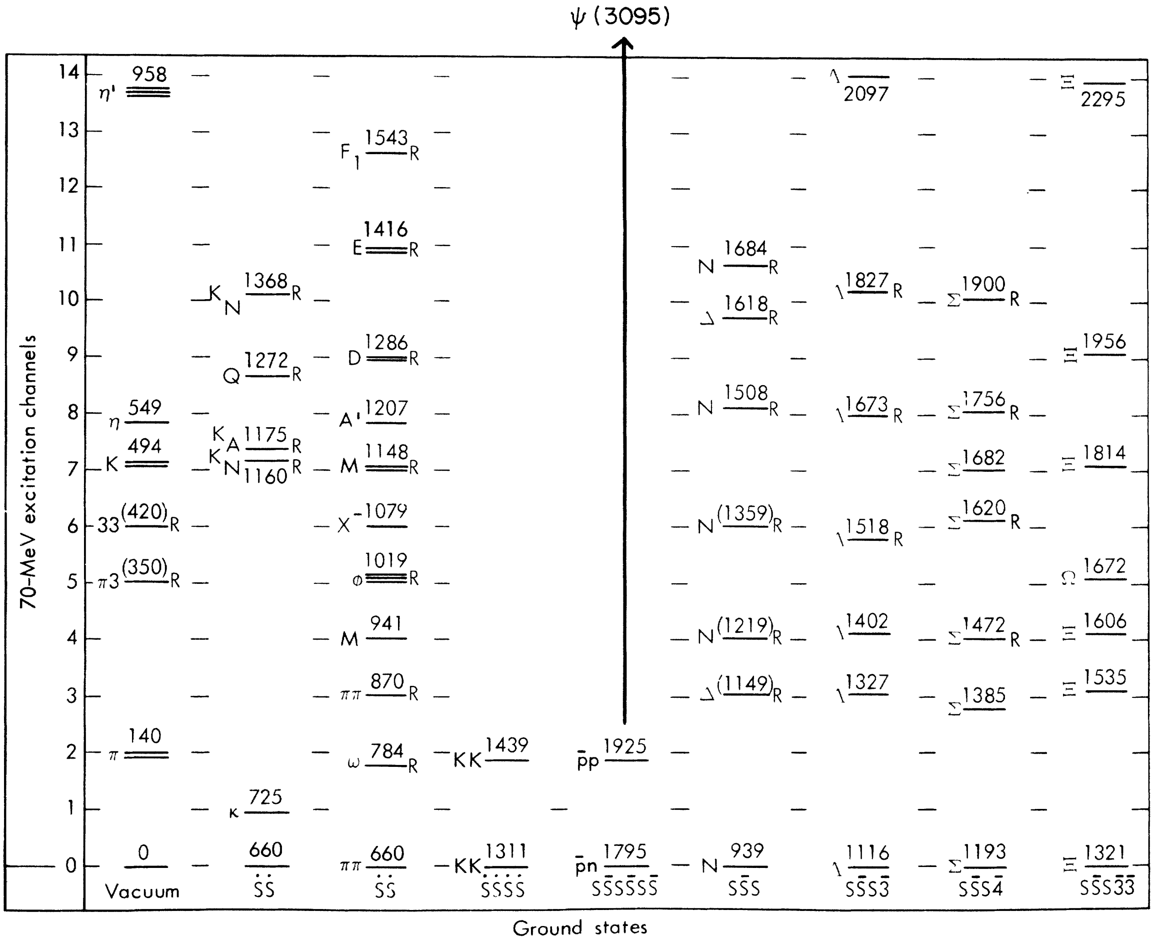

FIG. 1. This figure, which is taken from Fig. 8 of Ref. 1, is a mapping of the observed spectrum of narrow-width and S-state meson and baryon resonances, arranged as "excitation towers" based on a set of meson and baryon "ground states." Guided by a suggestion of A. S. Goldhaber and M. Goldhaber (Ref. 4), we have assigned the $\psi(3095)$ resonance to the excitation tower which contains the $\bar{p}n(1795)$ and $\bar{p}p(1925)$ resonances.

From the systematics of the light-quark model,[1,2] we would expect the ψ width to be $\Gamma \simeq 10$ MeV.[3] However, the actual ψ width, $\Gamma = 69 \pm 15$ keV,[5] is almost exactly one power of $\alpha^{-1} \simeq 137$ smaller than this value. Hence the inhibiting factor in the ψ decay appears to be electromagnetic, and the ψ lifetime fits into an empirical scaling in powers of α which has been previously observed[10] for the resonances with longer lifetimes (narrower widths) than the ψ.

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[1]M. H. Mac Gregor, Phys. Rev. D 9, 1259 (1974).

[2]M. H. Mac Gregor, Phys. Rev. D 10, 850 (1974).

[3]See Tables XXII and XXIII in Ref. 1.

[4]A. S. Goldhaber and M. Goldhaber, Phys. Rev. Lett. 34, 36 (1975).

[5]A. M. Boyarski *et al.*, Phys. Rev. Lett. 34, 1357 (1975); G. S. Abrams *et al.*, *ibid.* 34, 1181 (1975).

[6]L. Gray *et al.*, Phys. Rev. Lett. 26, 1491 (1971).

[7]This is the $\bar{p}p(1925)$ 8 peak reported D. Cline *et al.*, cited by the Particle Data Group, Rev. Mod. Phys. 43, S1 (1971). Also see G. Chikovani *et al.*, Phys. Lett. 22, 233 (1966); A. S. Carroll *et al.*, Phys. Rev. Lett. 32, 247 (1974); T. E. Kalogeropoulos and C. S. Tzanakos, *ibid.* 34, 1047 (1975); R. R. Burns *et al.*, Phys. Rev. D 11, 1004 (1975).

[8]In the light-quark model of Refs. 1 and 2, two distinct binding energies appear: B.E. ~ 4% [which can be observed experimentally in the $\bar{p}n(1795)$ resonance of Ref. 6] and B.E. ~ 0% (which can be observed as the linear mass intervals exhibited by the resonances

shown in Fig. 1 of the present paper). The 4% binding energies occur between (strange) particle and antiparticle light-quark basis states, and the ~0% binding energies occur for (nonstrange) quark states which have mixed particle and antiparticle substates. The "excitation quanta" of Fig. 1 are nonstrange excitations and thus have ~0% binding energies (with the quark masses as chosen in Refs. 1 and 2), whereas the $\bar{p}n$, N, Λ, Σ, and Ξ "ground states" of Fig. 1 involve 4% binding energies.

[9]See Table XI in Ref. 2 and the references contained therein. Evidence for a narrow meson resonance at this mass value is indicated primarily by a small interference dip which still persists in the A_2 meson in a number of uncontroverted experiments. From this interference effect (and also from the light-quark model), the $K_S K_S(1311)$ must have spin and parity $J^P = 2^+$, so that when it is combined with the $J^P = 1^-$ $\bar{p}n(1795)$ resonance the over-all spin and parity are consistent with the $J^P = 1^-$ spin and parity assignment (Ref. 5) for the $\psi(3095)$.

[10]M. H. Mac Gregor, in *Invited Papers*, 1971 Coral Gables Conference on Fundamental Interactions at High Energy, edited by M. Dal Cin, G. J. Iverson, and A. Perlmutter (Gordon and Breach, New York, 1971), Vol. 3, p. 75; Nuovo Cimento 20A, 471 (1974); UCRL Report No. 76300, Rev. 4, 1975 (unpublished).