Probe dependence of the quasielastic peak

J. Wambach*
Institut für Kernphysik, Forschungszentrum Jülich, D-5170 Jülich, Federal Republic of Germany
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Using sum rules and Fermi-liquid theory an explanation for the observed probe dependence of the quasielastic peak is offered.

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A strong probe dependence of the position of the quasielastic peak is found by comparing (e,e'), (p,p'), (p,n), and $(^3\text{He},t)$ reactions [1] (Fig. 1). This observation may have a very simple explanation.

Let me define the peak position via sum rules as

$$\langle \omega(q) \rangle = \sigma_1(q)/\sigma_0(q) , \tag{1}$$

where $\sigma_k(q)$ are energy-weighted moments of the cross section

$$\sigma_k(q) = \int d\omega\, \omega^k \sigma(q,\omega) . \tag{2}$$

Strictly speaking Eq. (1) defines the average energy transfer to the nucleus. If the energy spread is sufficiently small, however, as is the case in the quasielastic region, identification with the peak should be meaningful. Furthermore, I shall assume that the (q,ω) dependence of σ is well represented by a plane-wave impulse approximation (PWIA). For (e,e') scattering off a low Z target this is certainly justified. In hadronic reactions, on the other hand, distortions mainly attenuate the PWIA cross section without affecting the energy dependence considerably. Then distortion effects will cancel in the ratio $\langle \omega \rangle$. In PWIA the cross section for a given probe is given by

$$\sigma(q,\omega) = \sum_i |t_i(q,\omega)|^2 R_i(q,\omega) , \tag{3}$$

where R_i denotes the various spin-isospin components of the nuclear response function $(i = 1, \tau, \sigma, \sigma\tau)$ and t_i are the corresponding coupling vertices for the probe. I will further assume that the energy dependence of the vertices t_i is weak over the quasielastic bump which is justified for the kinematic range of the experiments in Fig. 1. Then one can make use of the well-known sum rule expressions [2]. For an $N = Z$ nucleus of mass number A

$$\begin{aligned} &\int d\omega\, R_i(q,\omega) = S_i(q) A , \\ &\int d\omega\, \omega R_i(q,\omega) = \left[\frac{1+F_1^{(i)}(q)/3}{1+F_1^{(1)}(q)/3} \right] \left[\frac{Aq^2}{2m} \right] , \end{aligned} \tag{4}$$

where $S_i(q)$ are the "liquid structure functions" and $F_1^{(i)}(q)$ the "back-flow" components of the particle-hole interaction [3]. The latter are velocity dependent and are thus closely related to exchange currents [4,5]. The nucleon effective mass at the Fermi surface is obtained as $m^*/m = 1 + F_1^{(1)}(0)/3$. With the two sum rules (4) and the energy independence of the vertices t_i one derives a compact expression for the peak position of a given probe

$$\langle \omega \rangle = \alpha(q) \frac{q^2}{2m} , \tag{5}$$

where

$$\alpha(q) = \frac{\sum_i |t_i(q)|^2 (1+F_1^{(i)}/3)/(1+F_1^{(1)}/3)}{\sum_i |t_i(q)|^2 S_i(q)} . \tag{6}$$

Some limit cases are obvious. Suppose one has a purely isoscalar probe, i.e., only t_1 is nonvanishing. Using the fact that for $q > q_c$ the liquid-structure functions are unity ($q_c = 2k_F$ in a Fermi gas) one then obtains

$$\langle \omega \rangle = q^2/2m \tag{7}$$

which is the famous f-sum rule in condensed matter

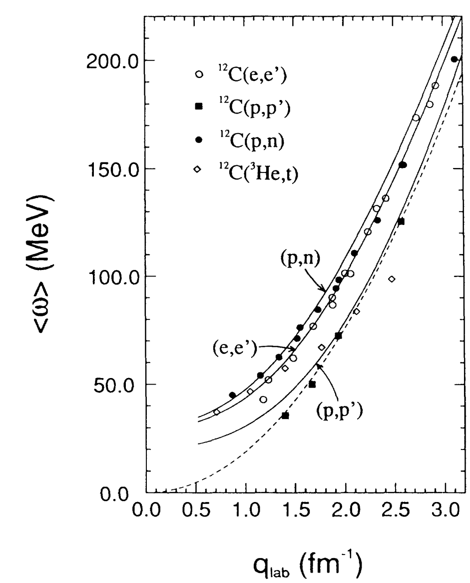

FIG. 1. Location of the quasielastic peak in ^{12}C as a function of three-momentum transfer for several probes [1]. The dashed line indicates the "naive" expectation $\langle \omega \rangle = q^2/2m$. The full lines give realistic estimates based on Eqs. (5) and (6).

*Also at Department of Physics, University of Illinois at Urbana-Champaign, 1100 West Green St., Urbana, IL 61081.

physics [2]. In fact, in (p,p') scattering at 800 MeV the projectile-target interaction is largely isoscalar and it is then expected that $\langle \omega \rangle = q^2/2m$, which is indeed found. For a purely isovector probe and $q > q_c$, on the other hand,

$$\langle \omega \rangle = \left[\frac{1+F_1^{(2)}(q)/3}{1+F_1^{(1)}(q)/3} \right] \frac{q^2}{2m} . \tag{8}$$

There is no reason for $F_1^{(1)}$ and $F_2^{(2)}$ to be same. In fact, G-matrix calculations predict opposite sign. Since $F_1^{(1)}(q) \leq 0^3$ I expect isovector probes to lie above the $q^2/2m$ line in Fig. 1. This is found for (p,n). Similar arguments apply for the charge response in (e,e'), as was already discussed in Ref. [4].

To quantify the arguments given above I have used realistic vertices t_i for the different probes, G-matrix predictions for the back-flow coefficients F_1^i, and liquid structure functions S_i, from the literature [6]. The resulting curves given in Fig. 1 agree quite well with observation.

In summary, based on sum rules and Fermi-liquid theory, I have offered a simple explanation for the probe dependence of the quasielastic peak position. The $(^3\mathrm{He},t)$ data remain unexplained, however.

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