Introduction to Nuclear and Particle Physics

Nuclear structure

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Nucleon excited states

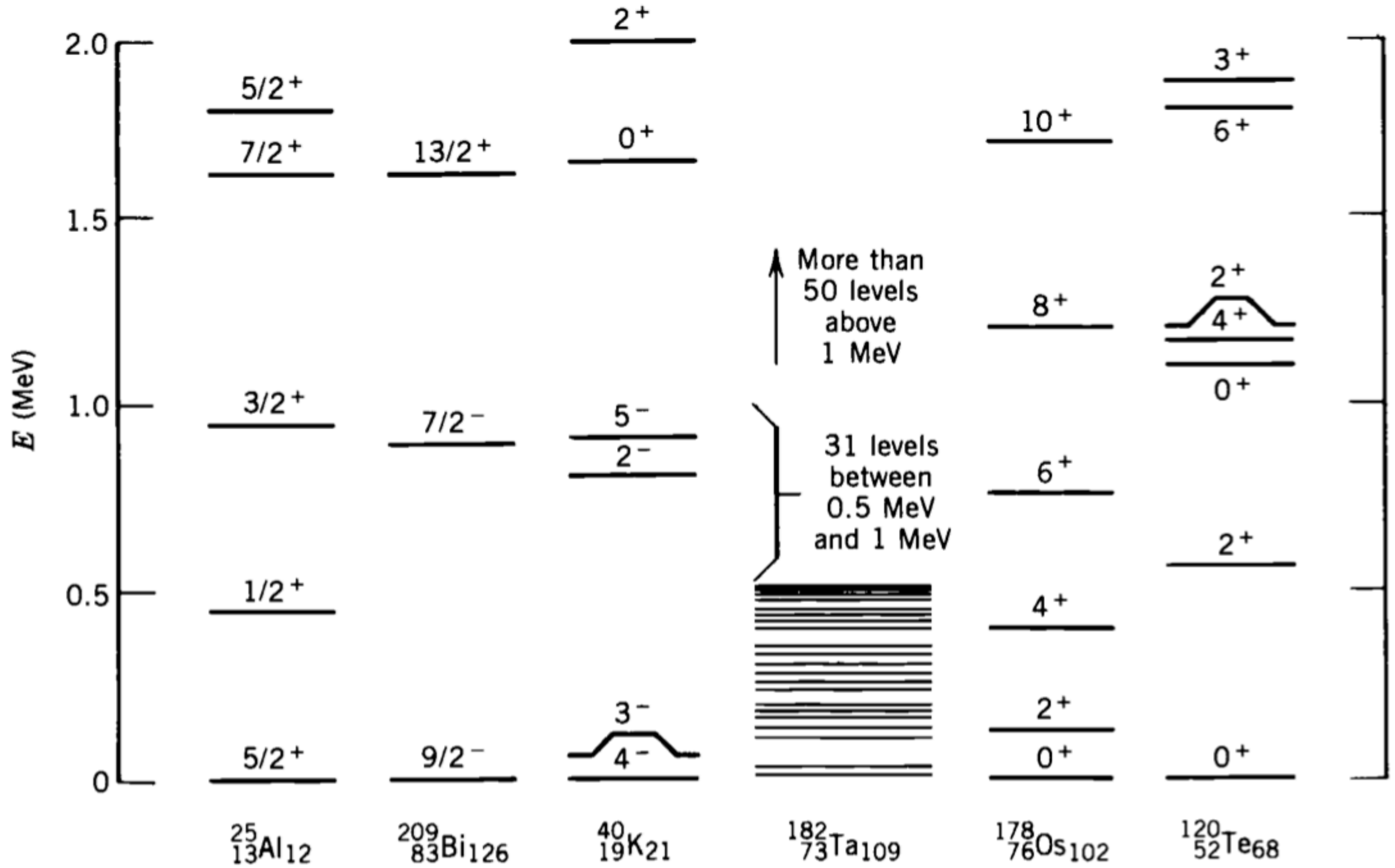


Figure 3.19 Some sample level schemes showing the excited states below 2 MeV. Some nuclei, such as ^{209}Bi, show great simplicity, while others, such as ^{182}Ta, show great complexity. There is a regularity associated with the levels of ^{178}Os that is duplicated in all even-Z, even-N nuclei in the range $150 \leq A \leq 190$. Structures similar to ^{120}Te are found in many nuclei in the range $50 \leq A \leq 150$.

Deuteron

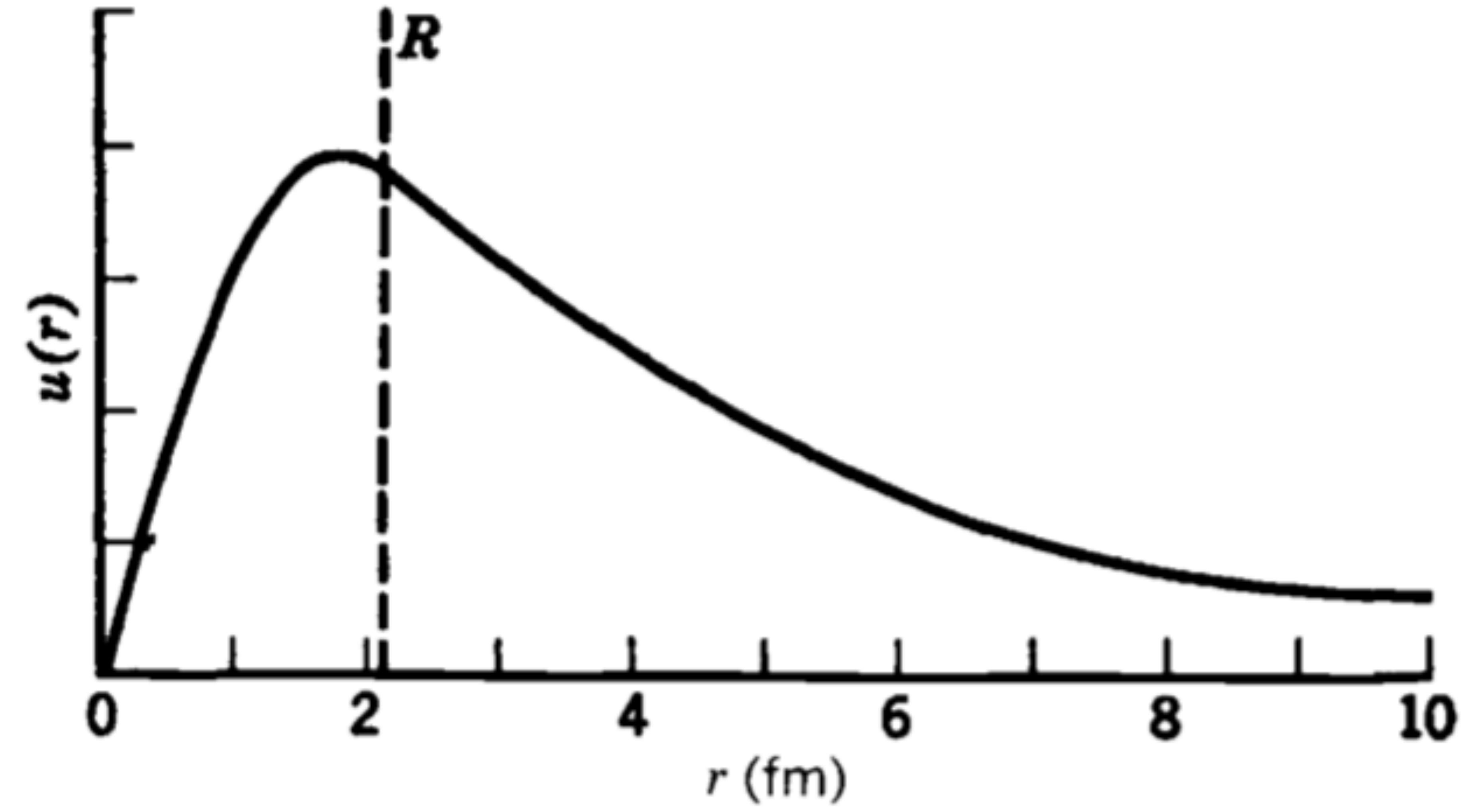
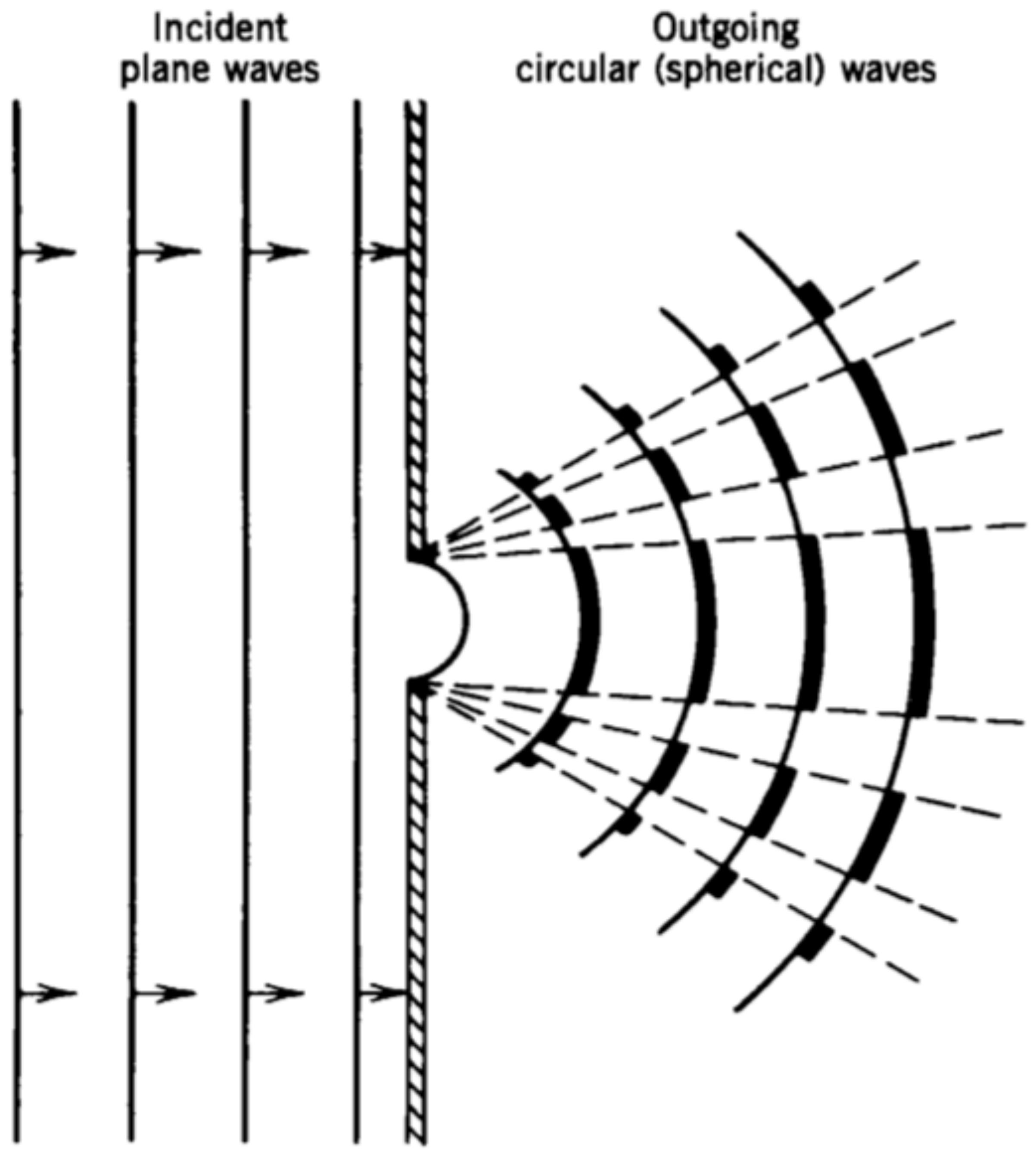
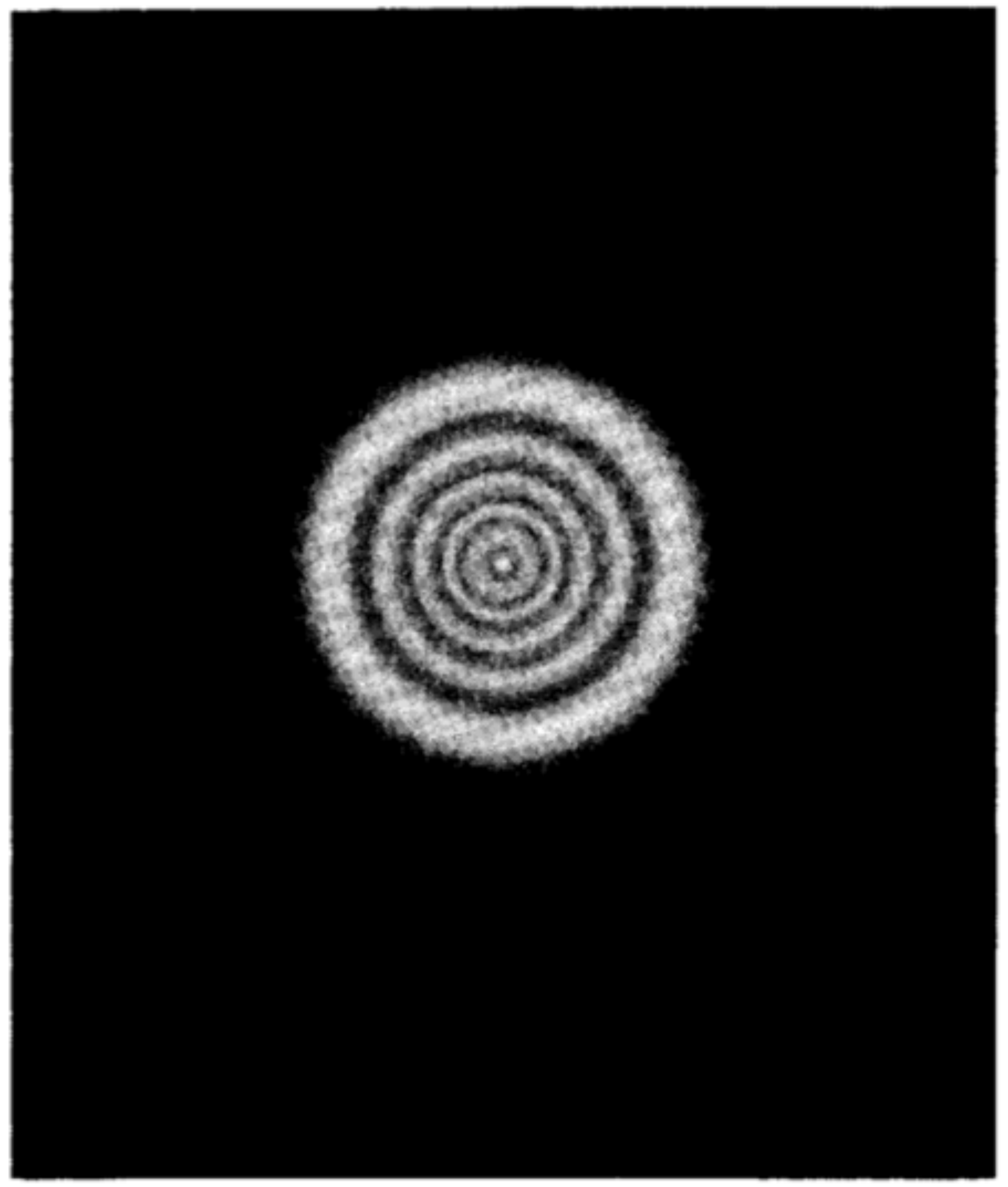


Figure 4.2 The deuteron wave function for $R = 2.1$ fm. Note how the exponential joins smoothly to the sine at $r = R$, so that both $u(r)$ and du/dr are continuous. If the wave function did not "turn over" inside $r = R$, it would not be possible to connect smoothly to a decaying exponential (negative slope) and there would be no bound state.

Diffraction





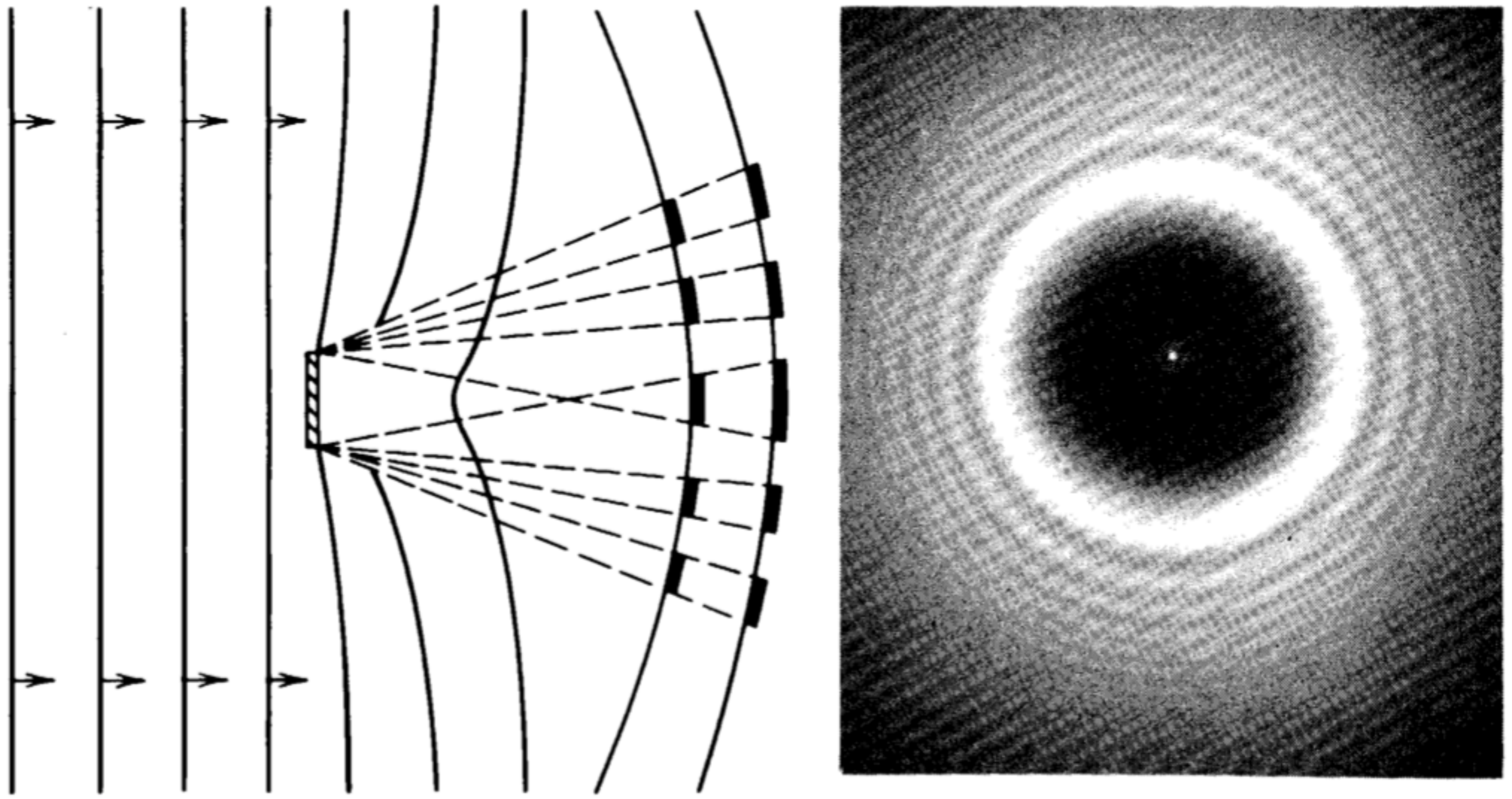


Figure 4.3 Representation of scattering by (top) a small opening and (bottom) a small obstacle. The shading of the wavefronts shows regions of large and small intensity. On the right are shown photographs of diffraction by a circular opening and an opaque circular disk. Source of photographs: M. Cagnet, M. Francon, and J. C. Thrierr, *Atlas of Optical Phenomena* (Berlin: Springer-Verlag, 1962).

Scattering

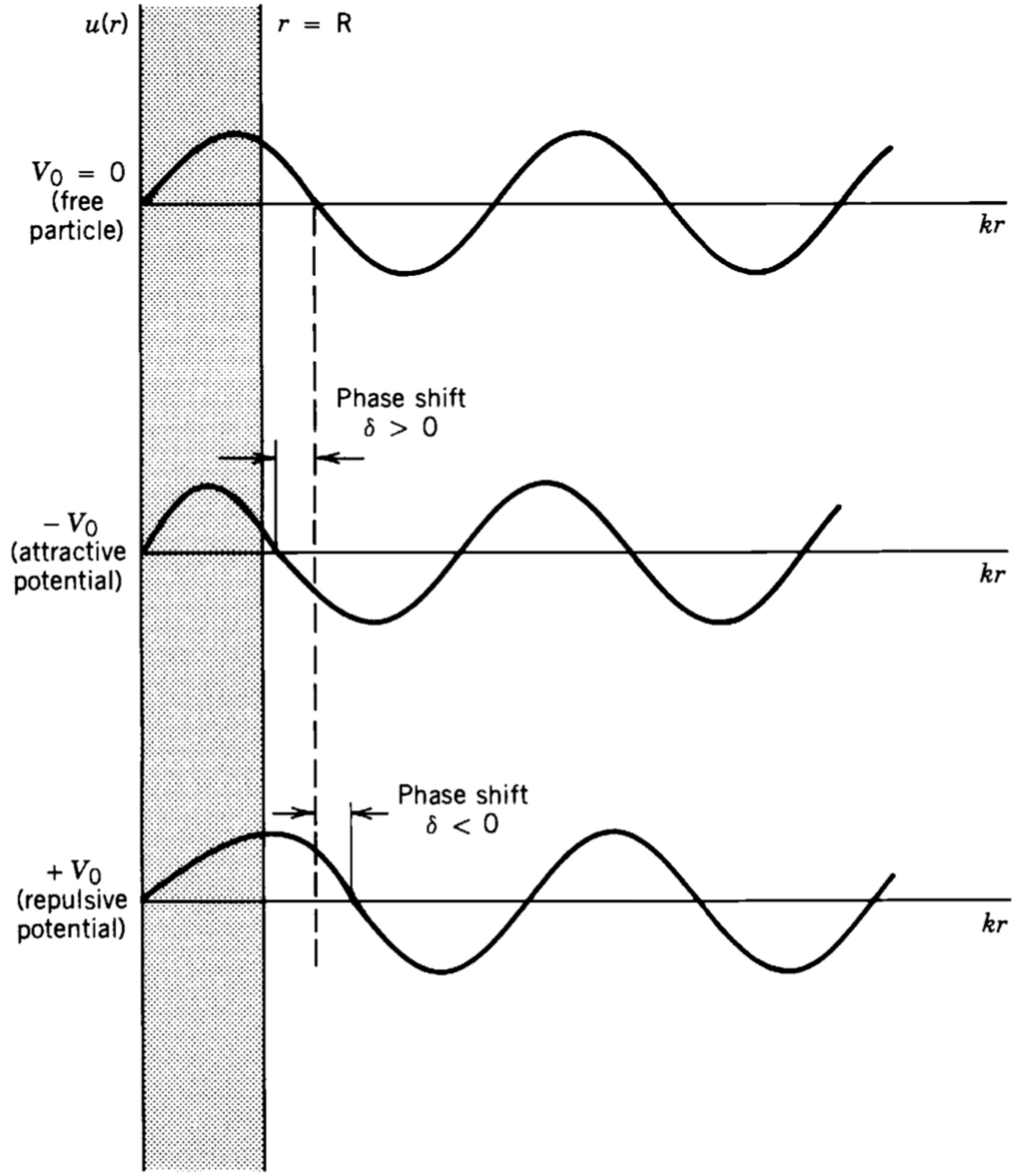


Figure 4.4 The effect of a scattering potential is to shift the phase of the scattered wave at points beyond the scattering regions, where the wave function is that of a free particle.

Scattering

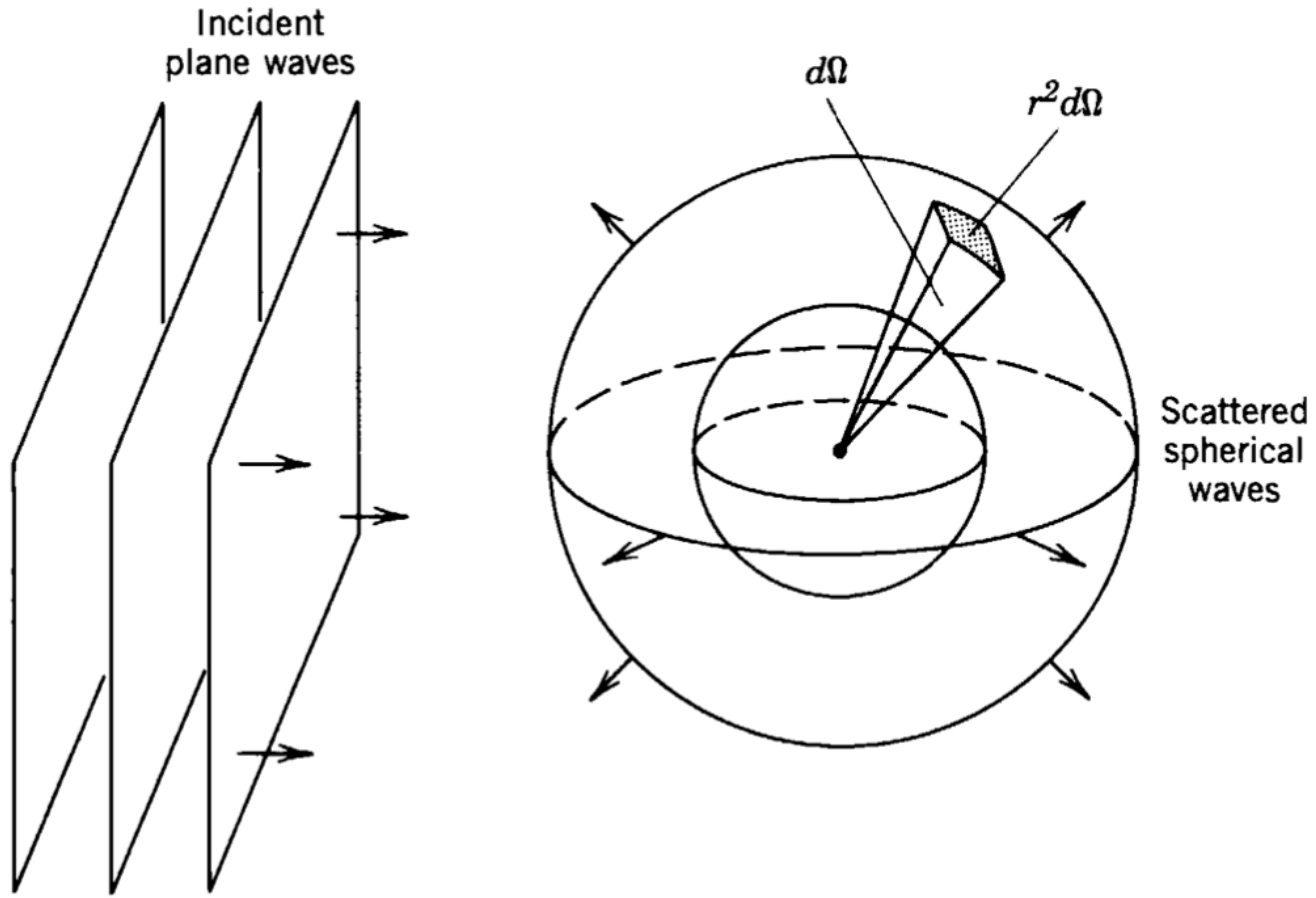


Figure 4.5 The basic geometry of scattering.

Scattering

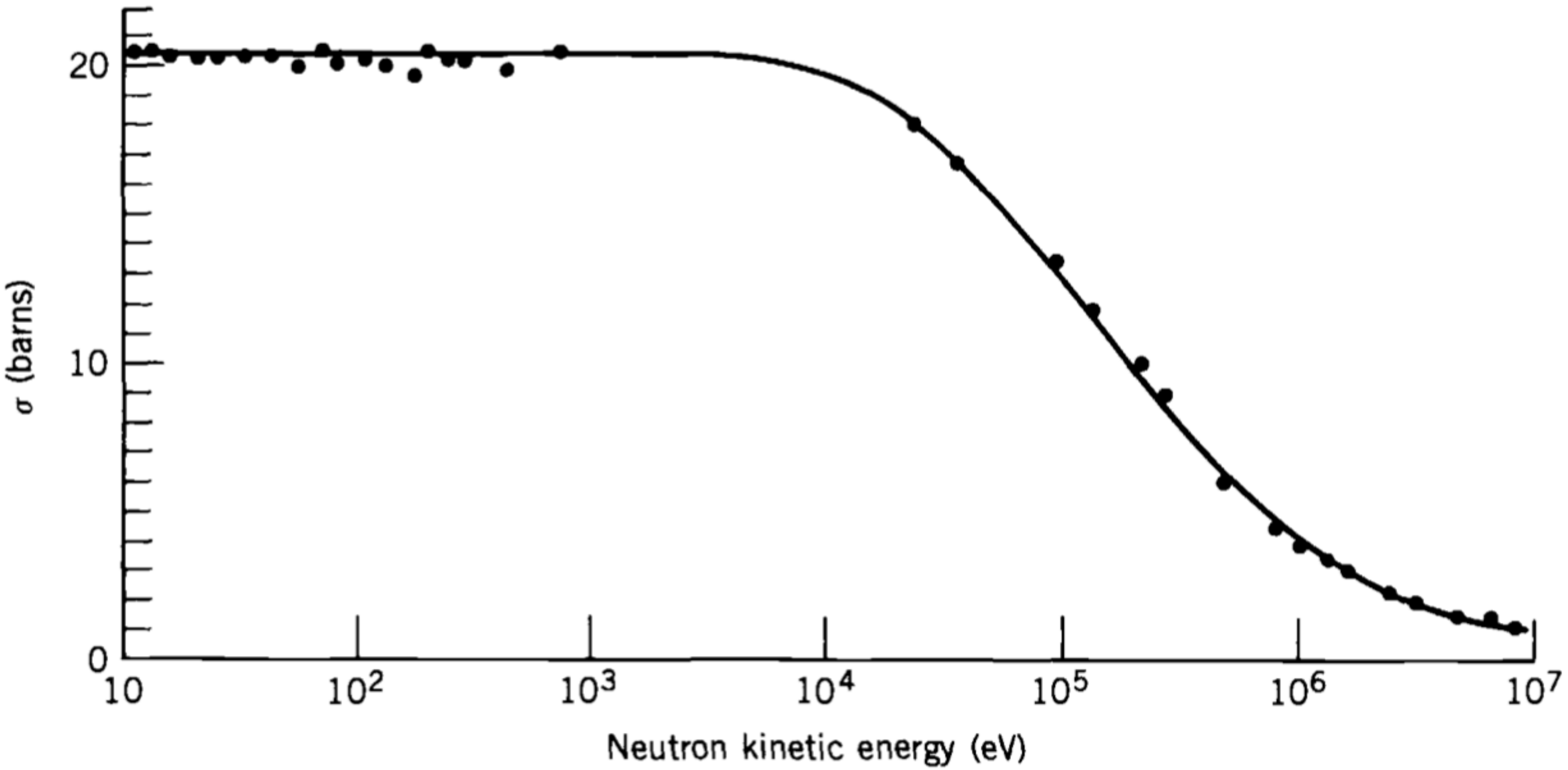


Figure 4.6 The neutron–proton scattering cross section at low energy. Data taken from a review by R. K. Adair, *Rev. Mod. Phys.* **22**, 249 (1950), with additional recent results from T. L. Houk, *Phys. Rev. C* **3**, 1886 (1970).

Scattering

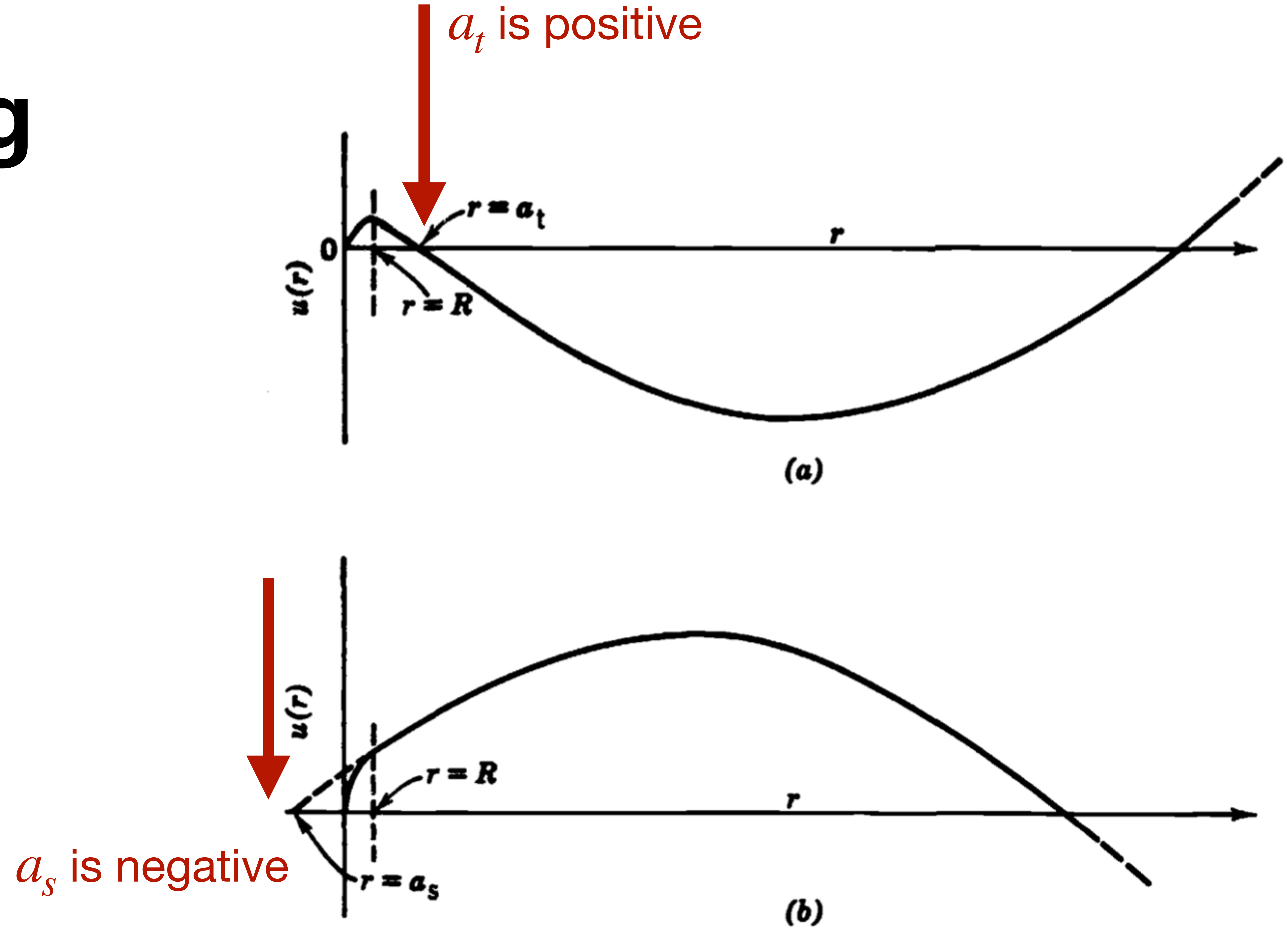


Figure 4.7 (*a*) Wave function for triplet np scattering for a laboratory neutron energy of ~ 200 keV and a well radius of 2.1 fm. Note the positive scattering length. (*b*) Wave function exhibiting a negative scattering length. This happens to be the case for singlet np scattering.

Scattering

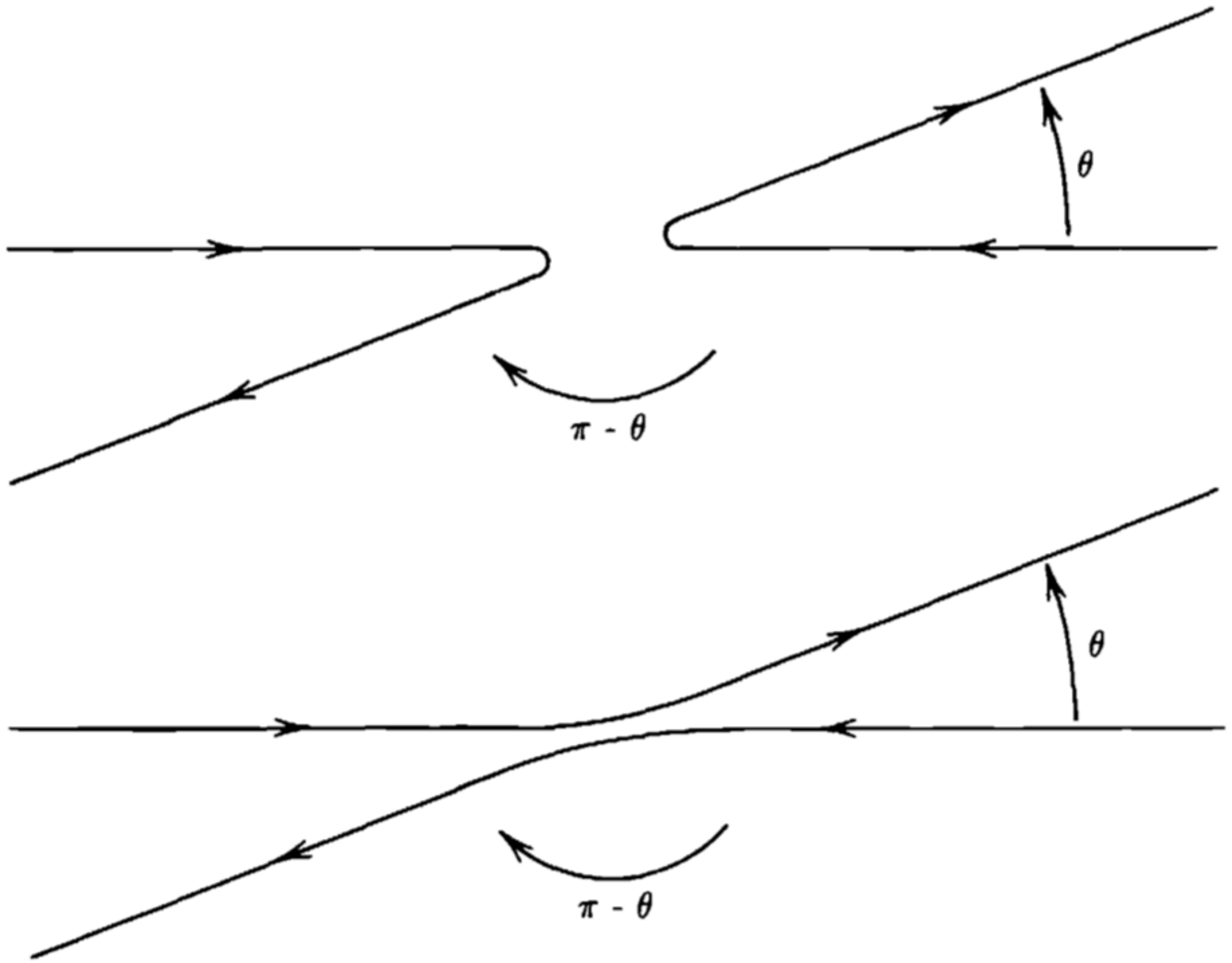


Figure 4.8 Scattering of identical particles in the center-of-mass system. One particle emerges at the angle θ and the other at $\pi - \theta$; because the particles are identical, there is no way to tell which particle emerges at which angle, and therefore we cannot distinguish the two cases shown.

p-p Scattering

$$\frac{d\sigma}{d\Omega} = \left(\frac{e^2}{4\pi\epsilon_0}\right)^2 \frac{1}{4T^2}\left\{\frac{1}{\sin^4(\theta/2)} + \frac{1}{\cos^4(\theta/2)} - \frac{\cos\left[\eta \ln \tan^2(\theta/2)\right]}{\sin^2(\theta/2)\cos^2(\theta/2)}\right.$$

$$- \frac{2}{\eta}(\sin\delta_0)\left(\frac{\cos\left[\delta_0 + \eta \ln \sin^2(\theta/2)\right]}{\sin^2(\theta/2)} + \frac{\cos\left[\delta_0 + \eta \ln \cos^2(\theta/2)\right]}{\cos^2(\theta/2)}\right)$$

$$\left. + \frac{4}{\eta^2}\sin^2\delta_0\right\} \tag{4.43}$$

p-p Scattering

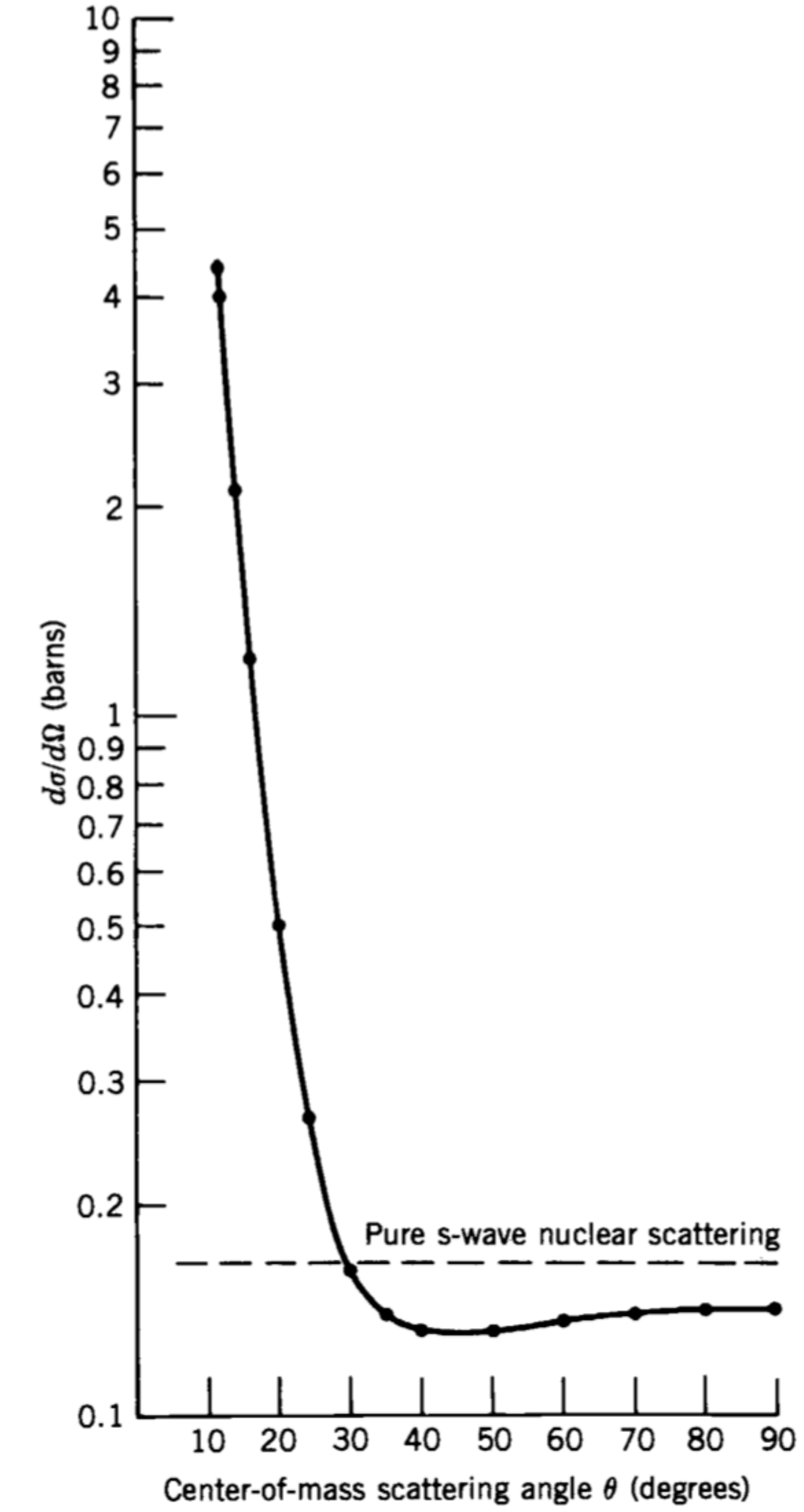


Figure 4.9 The cross section for low-energy proton–proton scattering at an incident proton energy of 3.037 MeV. Fitting the data points to Equation 4.43 gives the s-wave phase shift $\delta_0 = 50.966°$. The cross section for pure nuclear scattering would be 0.165 b; the observation of values of the cross section *smaller* than the pure nuclear value is evidence of the interference between the Coulomb and nuclear parts of the wave function. Data from D. J. Knecht et al., *Phys. Rev.* **148**, 1031 (1966).

p-p Scattering

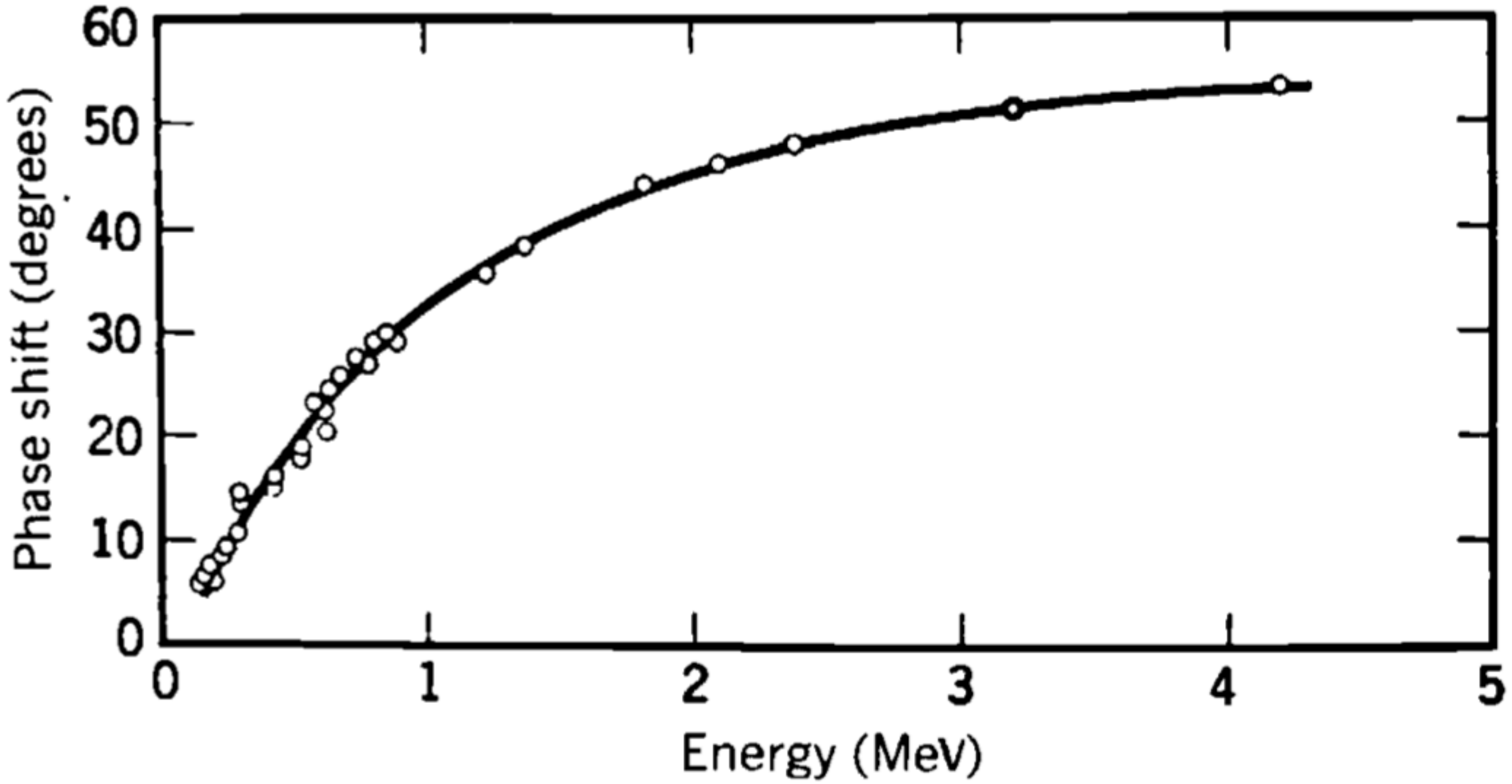


Figure 4.10 The s-wave phase shift for pp scattering as deduced from the experimental results of several workers.