the allowed electron capture is most likely to feed the $f_{7/2}f_{5/2}^{-1}(p_{1/2}^{-2})_0$ configuration in ^{206}Bi via a β transition between the spin-orbit partners $\pi f_{7/2} \rightarrow \nu f_{5/2}$. Hence the $f_{7/2}f_{5/2}^{-1}(p_{1/2}^{-2})_0$ configuration is assigned to the 1389.45-keV 1^+ state, which is most strongly fed from ^{206}Po with a logft value comparable to those for the corresponding electron captures of the odd-mass Po isotopes; the logft values are 6.0 for $^{205}\mathrm{Po}(\frac{5}{2}^-) \rightarrow {}^{205}\mathrm{Bi}$(1001.0 keV, $\frac{7}{2}^-$) and 6.6 for $^{207}\mathrm{Po}(\frac{5}{2}^-) \rightarrow {}^{207}\mathrm{Bi}$(992.3 keV, $\frac{7}{2}^-$). Mixing of $[(f_{5/2}^{-2})_0(f_{5/2}^{-2})_0]_\nu$ and $[(f_{5/2}^{-2})_0 \times (p_{3/2}^{-2})_0]_\nu$ is expected in ^{206}Po, giving rise to electron captures to $f_{7/2}f_{5/2}^{-1}(f_{5/2}^{-2})_0$ and $f_{7/2}f_{5/2}^{-1} \times (p_{3/2}^{-2})_0$ in ^{206}Bi, but these are expected to lie close to or higher than $Q_{EC} = 1.82$ MeV.

The other excited states of ^{206}Bi higher than 700 keV are hard to interpret at present. Appearance of an 8^+ state at 814.6 keV having no analog in ^{208}Bi suggests breaking of the neutron-hole pair in this energy region. Further study by other means is desirable in order to understand more fully the excited states of ^{206}Bi.

We are indebted to Professor K. K. Seth for suggesting the problem involved in the previous decay scheme of ^{206}Po.

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Finite-Range Calculations of the j Dependence of (^{12}C, ^{11}B) and (^{16}O, ^{15}N) on ^{62}Ni†

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Full finite-range calculations, including recoil effects exactly, have been performed for single-proton-transfer reactions on ^{62}Ni. Projectiles of ^{16}O and ^{12}C are considered. It is found that the ratios of cross sections leading to the ground and first excited states in ^{63}Cu are in good agreement with experiment. This is not true when recoil is neglected.

In a recent paper,[1] a study of the j dependence of heavy-ion–induced reactions was reported. In particular, ^{12}C and ^{16}O projectiles (at energies of 78 and 104 MeV, respectively) were used to transfer protons to states in various nuclei of $j_>$ ($j = l + \frac{1}{2}$) and $j_<$ ($j = l - \frac{1}{2}$). Kovar *et al.*[1] attempted to calculate the ratios of these cross sections by the use of the finite-range computer code RDRC[2] (which neglects recoil) and were unsuccessful. Overpredictions by factors of 2–10 were found. It was argued that the no-recoil feature of the calculations was responsible. The purpose of this Letter is to report that, indeed, the use of the exact finite-range computer code MERCURY,[3,4] which also includes recoil exactly, provides reasonable ratios for one of the targets studied (^{62}Ni).

Differential cross sections were calculated here for proton transfer to the ^{63}Cu ground state and its first excited state. These levels were assumed to be pure single-particle states with configurations $2p^{3/2}$ and $2p^{1/2}$, respectively. The distorted waves were generated by use of a volume Woods-Saxon plus Coulomb potential. The parameters characterizing the interaction are shown in Table I. The first set was found by Becchetti *et al.*[5] to match the elastic scattering of both ^{16}O and ^{12}C at forward angles and for targets in the region of the nuclei considered here. The energy, however, was 38 MeV (60 MeV) for ^{12}C (^{16}O) which is about half that used here. The second set was picked somewhat arbitrarily to test the

TABLE I. Parameters in the calculations reported. In all cases, a volume Woods-Saxon potential was used. For the distorted waves, the parameters shown are a complex strength of $-V-iW$, a diffuseness a, and a radius parameter $R=r_0(A_1^{1/3}+A_2^{1/3})$. In the bound states, $R=r_0A^{1/3}$.

	Set	V (MeV)	W (MeV)	r_0 (fm)	a (fm)	r_0^c (fm)
Distorted waves	I	40.0	15.0	1.3	0.50	1.3
	II	80.0	10.0	1.2	0.65	1.2
Bound states				1.2	0.65	1.2

effect on the cross sections of a different choice. A single set was used for both initial and final states and for both projectiles.

The bound-state wave functions were also found using a volume Woods-Saxon potential, but the strength was adjusted to give the correct asymptotic behavior for a particle bound by the physical separation energy. The relevant parameters are also given in Table I.

The ratios of the cross sections were found at angles corresponding to grazing collisions at a radius of $\sim 1.7(A_1^{1/3}+A_2^{1/3})$ fm ($\sim 20°$ in all cases). The use of parameter set II gave a highly oscillatory cross section. However, the ratios found were approximately true point by point in the angular distribution. These ratios are shown in Table II for the two parameter sets and as given experimentally.[1] As can be seen, the most extreme case is in error by ~35%. In no case is the disagreement as large as a factor of 2, corresponding to the best case for the no-recoil analysis.

In Fig. 1 is shown the differential cross section as found for the ^{12}C projectile leading to the ground state of ^{63}Cu. The second set of parameters gives the previously mentioned oscillatory behavior, while the first set reproduces the cross section as found experimentally in Ref. 1. A structureless cross section, except for a peak at the grazing angle, has been seen in other heavy-ion reactions.[6,7]

TABLE II. Grazing-angle cross-section ratios for $^{62}Ni(a,b)^{63}Cu$ for the single-particle states indicated. The last column is the ratio of the two numbers in the preceding column and is shown since it eliminates all spectroscopic factors. Experimental data are from Ref. 1.

	a	b	E_a (MeV)	$\frac{2p^{3/2}}{2p^{1/2}}$	$\frac{^{16}O}{^{12}C}$
I	^{16}O	^{15}N	104	2.8	1.33
	^{12}C	^{11}B	78	2.1	
II	^{16}O	^{15}N	104	3.4	1.79
	^{12}C	^{11}B	78	1.9	
Expt	^{16}O	^{15}N	104	4.10	1.32
	^{12}C	^{11}B	78	3.10	

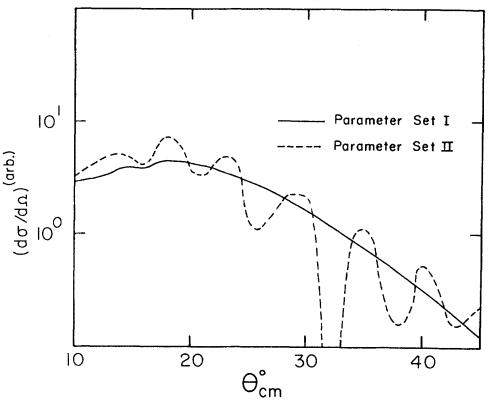

FIG. 1. Differential cross section for $^{62}Ni(^{12}C,^{11}B)^{63}Cu(g.s.)$, $E(^{12}C)=78$ MeV, with differing parameter sets. The cross section is given in arbitrary units, but the positions of the two curves relative to each other are as shown.

It has been shown that neglecting recoil can cause extreme oscillatory behavior in differential cross sections.[8] As may be seen in Fig. 1, the same structure may be produced by the choice of optical parameters.

A more thorough calculational study of j dependence should perhaps await (1) more detailed information on the transfer cross sections, and (2) accurate information on the elastic scattering at these energies. It is claimed, however, that this paper shows that correct relative normalizations can be calculated if recoil effects are included exactly.

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On-Line Mass-Spectrometric Measurement of the Masses of Neutron-Rich Sodium Isotopes

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Using an on-line mass spectrometer, we have measured directly, to an accuracy of 150 to 500 keV, the masses of $^{27-30}$Na produced in the reaction of 24-GeV protons on uranium.

Light nuclei with a large excess of neutrons have been produced using the reaction of high-energy protons on heavy targets[1,2] or in complex transfers from heavy-ion–induced reactions.[3] In most of the cases only the existence (i.e., particle stability) of the more exotic nuclei is known. This information is of particular value if the calculated limits of nuclear stability can be tested this way. Some experiments also give other ground-state characteristics such as half-lives[2] or masses.[4] The ground-state mass measurements reported to data are based on transfer reactions[4,5] or β end-point measurements[6] and appear to be limited to nuclei of $T_z \leq 3$ (for $Z \lesssim 15$).

In this paper we want to report for the first time direct mass measurements with an on-line mass spectrometer. These first results concern sodium isotopes (^{27}Na to ^{30}Na) produced in the reaction of 24-GeV protons on uranium at the CERN proton synchrotron. While ^{30}Na is already $T_z = 4$, there is a definite possibility to extend these measurements even further from stability.

The importance of this point lies in the fact that the mass calculations that serve to predict the stability of very neutron-rich nuclei all derive their parameters from a region of nuclei with measured masses near the valley of β stability. Very distant extrapolations can then lead to sizable errors as can be seen by observing that the predictions of different mass formulas[7] can differ between themselves by several MeV for nuclei of $T_z \geq 3$. Hence the measurement of masses of nuclei far from stability can lead to a very severe test of the validity of mass formulas even when the measurements have an accuracy of only 200–500 keV. Measurements to this accuracy for sodium isotopes (about 10^{-5}) can be obtained with a spectrometer with a resolving power of only 500 [full width at half-maximum (FWHM)] by measuring the centroid of the peaks to an accuracy of $\frac{1}{2}\%$ of their widths.

On-line mass spectrometry had already been used to identify new isotopes and measure their half-lives.[2] The essence of the technique is the capture of energetic recoils from the reaction in heated graphite foils from which alkali elements diffuse very quickly to be ionized on a hot rhenium surface. A schematic of the experiment is shown in Fig. 1. For the rest of the discussion it is appropriate to think of the instrument as an ordinary mass spectrometer with a special surface-ionization ion source that is loaded with the short-lived nuclei of interest at regular time intervals (every 10 sec) by the interaction of intense ($\sim 10^{12}$) proton bursts with a target consisting of about 2 g/cm^2 of uranium. The resulting ions are accelerated with about 10 kV and analyzed by a slightly inhomogeneous ($n = 0.23$) magnetic prism ($\varphi = 90°$, $r = 35$ cm). Two triplets of electrostatic quadrupole lenses are used to refocus the ions passing the exit slit of the spectrometer onto an electron multiplier located in a well shielded area and able to detect single ions.

The measurement of masses rests on the same theorem that is used in high-resolution mass measurements[8]: two ions A^+ and B^+ of masses M_A and M_B follow the same trajectory in the spectrometer if the magnetic field configuration remains constant and all electrostatic potentials are changed to satisfy the ratio

$$M_A/M_B = V_B/V_A. \quad (1)$$