RESONANCES IN THE CAPTURE OF PROTONES BY SULFUR 33

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ABSTRACT

Protons from a Van de Graaff generator have been used to bombard targets of S^{33}. The reaction S^{33} (p, γ) Cl^{34} has been studied by observing the gamma-ray yield as a function of the proton energy in the region between 1100 and 1550 kev. Resonance maxima occur for protons with energies of 1152, 1211, 1262, 1434, 1456, and 1525 kev.

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1. Introduction.

This investigation was conducted to determine the resonances in the capture of protons by S^{33} over the proton energy range of 1.10 to 1.55 Mev (laboratory system). Inasmuch as the target material consisted of sulfur enriched to 22 percent S^{33} by weight, it was also necessary to investigate the resonance capture of protons by natural sulfur over the same proton energy range so that each resonance might be assigned to either S^{33} or to a normal isotopic mixture of natural sulfur.

When sulfur is bombarded by protons one reaction which may occur is the formation of a compound nucleus in an excited state. The specific reaction involved may be written as:

$$S^{33} + p \rightarrow \left[Cl\ 34^*\right]$$

If protons of low energy are used, gamma radiation may be emitted by the excited compound nucleus during de-excitation to successively lower energy states. By observing the yield of these gamma-ray transitions it is thus possible to determine resonances in S^{33} as a function of the proton energy. The compound nucleus Cl^{34} is radioactive and may decay[1] by β^+ emission to S^{34} from the ground state with a half-life of 1.5 seconds and from the isomeric state with a half-life of 32 minutes.

The targets used in this investigation were prepared by vacuum-coating CdS on a tantalum metal backing. CdS enriched

[1] D. Stominger, J. M. Hollander, and G. T. Seaborg, Phys. Rev. 30, 585 (1958)

to 22% S^{33} as well as CdS prepared from natural sulfur were employed. Isotopic analysis of the S^{33} enriched CdS was reported[2] as follows: S^{32}, 73.6%; S^{33}, 22.1%; S^{34}, 4.2%.

Previous investigations of gamma-ray radiation from the proton capture by sulfur have been reported by Hanscome and Malich.[3] Resonances were observed in targets consisting of a normal isotopic composition of sulfur over a proton energy interval of 0.9 to 2.1 Mev at about 1.37, 1.61, 1.69, 1.80 and 1.86 Mev. Recent investigation of the S^{32} (p,γ) Cl^{33} reaction has been reported[4] by Muller, Gelsema, and Endt envolving the production of Cl^{33} at a bombarding proton energy of 594 kev using natural CdS targets and also enriched CdS^{32} targets. Two resonances at 449 and 513 kev observed from the S^{33} (p,γ) Cl^{34} reaction were reported[4] by Van der Leun.

[2]Oak Ridge National Laboratory Test Analysis Rpt. on Batch No. G. B. 758(a).

[3]T. C. Hanscome and C. W. Malich, Phys. Rev. 82, 304 (1951).

[4]Th. Muller, E. S. Gelsema, and P. M. Endt, Physica 24, 577 (July 1958).

2. Resonance and Decay Phenomena.

The formation of a compound nucleus is believed to result from the energy exchange of the incident particle with all of the nucleons in the target nucleus. The compound nucleus thus formed is independent of its mode of formation and may decay by particle emission, including emission of the incident particle and the original target nucleus in its ground state (compound elastic scattering). If break-up of the compound nucleus is by gamma-ray emission, the gamma-ray yield observed may be measured as a function of the incident particle's energy. Resonances are evidenced by the occurrences of maxima in the gamma-ray yield at different and discrete incident particle energies. This leads to the determination of the excited energy levels of the compound nucleus. An extended analysis of the resonance phenomena has been given by Fowler, Lauritsen and Lauritsen.[5]

In the case of resonance in the capture of protons by S^{33} the following reaction and subsequent break-up of the compound nucleus may result over the proton energy range of 1.10 to 1.52 Mev:

$$S^{33} + p \rightarrow \left[Cl^{34*}\right] \rightarrow Cl^{34M} + \gamma \rightarrow S^{34*} + \beta^{+} \rightarrow S^{34} + \gamma \qquad (1)$$

$$Cl^{34} + \gamma \rightarrow S^{34} + \beta^{+} \qquad (2)$$

$$S^{33*} + p' \rightarrow S^{33} + \gamma \qquad (3)$$

$$S^{33} + p \qquad (4)$$

[5] W. A. Fowler, C. C. Lauritsen, and T. Lauritsen, Rev. Mod. Phys. 20, 236 (1948).

In the investigation conducted, detection of the gamma-radiation produced by the first two series of reactions listed above was of primary concern. The third reaction is considered to contribute only small fractions of the gamma-ray intensity, while the latter reaction could not be observed with the experimental apparatus employed. Other reactions involving the ejection of heavier nucleons are not energetically possible considering the low proton energies used in this investigation.

3. Apparatus and Procedure.

Targets were bombarded using the proton beam of a 2-Mev Van de Graaff generator. The ensuing gamma radiation was detected by means of a scintillation crystal. The principal components of the accelerator system include a pressure-insulated Van de Graaff electrostatic generator and mount, a vacuum system, a beam-analyzing system with electronic feed-back voltage stabilizer and stabilized magnetic current power supply, and a remote control console. The ion source is of the RF type, with allied power supplies and controls, placed in the high potential terminal of the generator to produce positively charged nuclear particles by utilizing hydrogen. This arrangement affords a controllable source of constant potential for the acceleration of particles to high energies.

The beam-analyzing system, employing a deflecting magnet with analyzing chamber, power supply, and controls, separated high-energy particles into three beams, each with particles of a different mass. This permitted selection of the Mass 1, 2 or 3 component of the ion beam and subsequent direction of this component to the exit portal.

The target, placed at the terminal end of a Faraday cage which collected incident protons, was a disk stamped from 5-mil tantalum sheet forming a backing for sulfur. The disks were coated in a vacuum chamber by evaporating CdS from a tungsten boat.

Each target was mounted on an individual open-ended glass tube by sealing it permanently with Glyptal cement.

A plastic jacket closed at one end was fabricated to fit over the target and glass tube. This served to insulate the target current lead-out wire from the scintillation crystal housing and also as a means of enclosing a small plastic hose used to supply cooling air to the end of the target. Electrical contact with the target was achieved by means of a small spring butted against the target and held in place by the end of the plastic jacket. After insuring that the proton beam was centered on the target, the entire target assembly was inserted into the well of the scintillation crystal to insure maximum possible detection of emergent gamma-rays. Low pressure compressed air was forced through a drying chamber filled with silica-gel. The dried air was cooled by passage through a coil immersed in a salted ice solution. The cooled air was delivered to the target through the small plastic hose previously mentioned. During bombardment cooling of the target was necessary to avoid rapid loss of the CdS coating.

The gamma-rays were detected with a scintillation counter consisting of a DuMont 6269 photomultiplier tube and a NaI (Tl) crystal in an Argonne-type crystal mount. The pulses from the photomultiplier were amplified with a Model N302 non-overload amplifier (Hammer Electronics Co.), counted on a Model 1283 atomic glow scaler (Baird Associates-Atomic Instrument Co.) and observed simultaneously on a Tektronix Type 531 oscilloscope. The scintillation counter was shielded by lead bricks to reduce the high background

radiation. Scalers, amplifiers and allied controls were located adjacent to the console, enabling one operator to acquire all data at one location. The magnet current was calibrated in terms of proton energy by use of the prominent resonances in the Al^{27} (p,γ) Si^{28} reaction over a proton energy range of 0.991 to 1.320 Mev.

The energy range for proton bombardment was between 1.10 Mev and 1.55 Mev, employing Mass - 1 in steps of approximately 0.001 amperes of magnet current, corresponding to proton energy steps of 1.70 kev. Three pulse height discriminators were biased to selected energies for comparison. One was biased just below 0.511 Mev with a 1 Mev window on differential to detect the annihilation quanta resulting from the B decay from the ground state of Cl^{34} to S^{34}. A second was biased at 6 Mev with a 1 Mev window to detect possible decay of Cl^{34*} directly to its ground state. The third was biased on integral with a base line at 2.5 Mev to reject pulses due to background radiation and observe possible resonances due to S^{33}. Suspected resonances revealed by rough plots were then rechecked and traversed in shorter steps. Gamma-ray spectra resulting from the decay of compound nuclei were obtained by photographing the pulse-height distributions at all resonance peaks with a Polaroid Camera mounted on the oscilloscope.

Calibration of the pulse height amplifiers as well as the oscilloscope was accomplished with a radioactive source

of Zn^{65} for the 511-kev level and Co^{60} for the 2.5-Mev level. A lithium fluoride target was bombarded at resonance energy values to yield the characteristic 6 and 7 Mev gamma-ray lines. Photographs of the gamma-ray spectrum produced by the above listed calibration sources served to identify the prominent spectral lines produced by the sulfur targets. An additional use was made of the fluorine target. The 1092 kev proton energy resonance of the F^{19} (p,α) O^{16} reaction served as a known point of departure while traversing the proton energy range. Once bombardment of the sulfur target had been initiated from this point of departure the magnet current was progressively advanced to insure that the magnetic analyzer remained on the same hysteresis loop.

Excitation curves were constructed from the gamma-ray yields obtained from the bombardment of targets composed of CdS and CdS^{33}. Resonances were attributed exclusively to S^{33} wherever the CdS^{33} target produced maximum yields and the CdS target produced no perceptible yield. Wherever resonances produced from the CdS and CdS^{33} targets appeared in coincidence the resonances were attributed to either S^{32} or S^{34}.

4. Results.

Gamma-ray yields were obtained as a function of proton bombarding energies varying between 1.10 and 1.55 Mev (laboratory system). Figure 1 is the excitation curve obtained with a typical CdS^{33} target. Correction for background radiation, obtained by measuring the gamma-ray yield from a blank target bombarded by protons over the energy range considered, has been applied to this excitation curve. The proton energies at which resonance maxima appear together with relative gamma-ray yield are listed in Table I.

TABLE I

Proton energy at resonance (Mev)	Relative yield
1.152 ± .002	4.6
1.211 ± .002	14.2
1.262 ± .002	7.0
1.434 ± .002	3.3
1.456 ± .002	2.9
1.525 ± .002	6.1

Proton energies at which resonance maxima appear for the reaction S^{33} (p, γ) Cl^{34} and corresponding relative yields obtained.

The relative gamma-ray yields are computed from the excitation curve obtained with the bias of the discriminator set to reject all pulses below 2.5 Mev. The small shoulder appearing at a proton energy of 1.211 Mev could be resolved only

when the bias of the discriminator was set to reject pulses below 3.0 Mev. The proton energies at which resonance maxima appear have been computed from the location of the F^{19} (p,α) O^{16} resonance at 1.092 Mev and the subsequent application of a slope of 1.70 Mev/ampere. The accuracy of the results obtained is contingent upon the accuracy with which the 1092 kev fluorine resonance could be determined as well as the accuracy and inflexibility of the slope of the calibration curve obtained from prominent aluminum resonances. Based upon the observed variance of the primary calibration resonance and a constant slope of the calibration curve, the probable random error ascribed to each resonance energy reported is considered to be $\pm$ 2 kev.

The gamma-ray yield obtained at each resonance varied considerably with each target used. This is attributed to the non-uniform thickness of material vacuum coated onto each target backing. Since one target was used for each 210 kev of proton energy range, reduction in gamma-ray yield due to loss of target material was not considered of major importance. This was substantiated by successively traversing a particular resonance with the same target in place. No significant change in the height or shape of the gamma-ray yield curve was observed. Final relative yield values were based on the maximum gamma-ray yields obtained with a single target. On this occasion only the resonance energy regions obtained previously were examined. Intermediate energies were omitted in order that any effect of target life on the

yield curve would be minimized.

The three peaks labeled S on the excitation curve in Figure 1 are due to resonances in the normal isotopic composition of sulfur. The targets prepared from the sulfur enriched in S^{33} contained a proportionate percentage of S^{34} as those prepared from natural sulfur, therefore resonances due to S^{32} or S^{34} cannot be distinguished separately and must be considered due to either.

The two peaks labeled F on the excitation curve in Figure 1 are very probably due to fluorine. The proton energies at which resonances were observed, 1342 and 1372 kev respectively, correspond to fluorine resonances reported at these energies. Photographs of the pulse height of the gamma-ray spectrum at these resonance values further substantiate the presence of fluorine.

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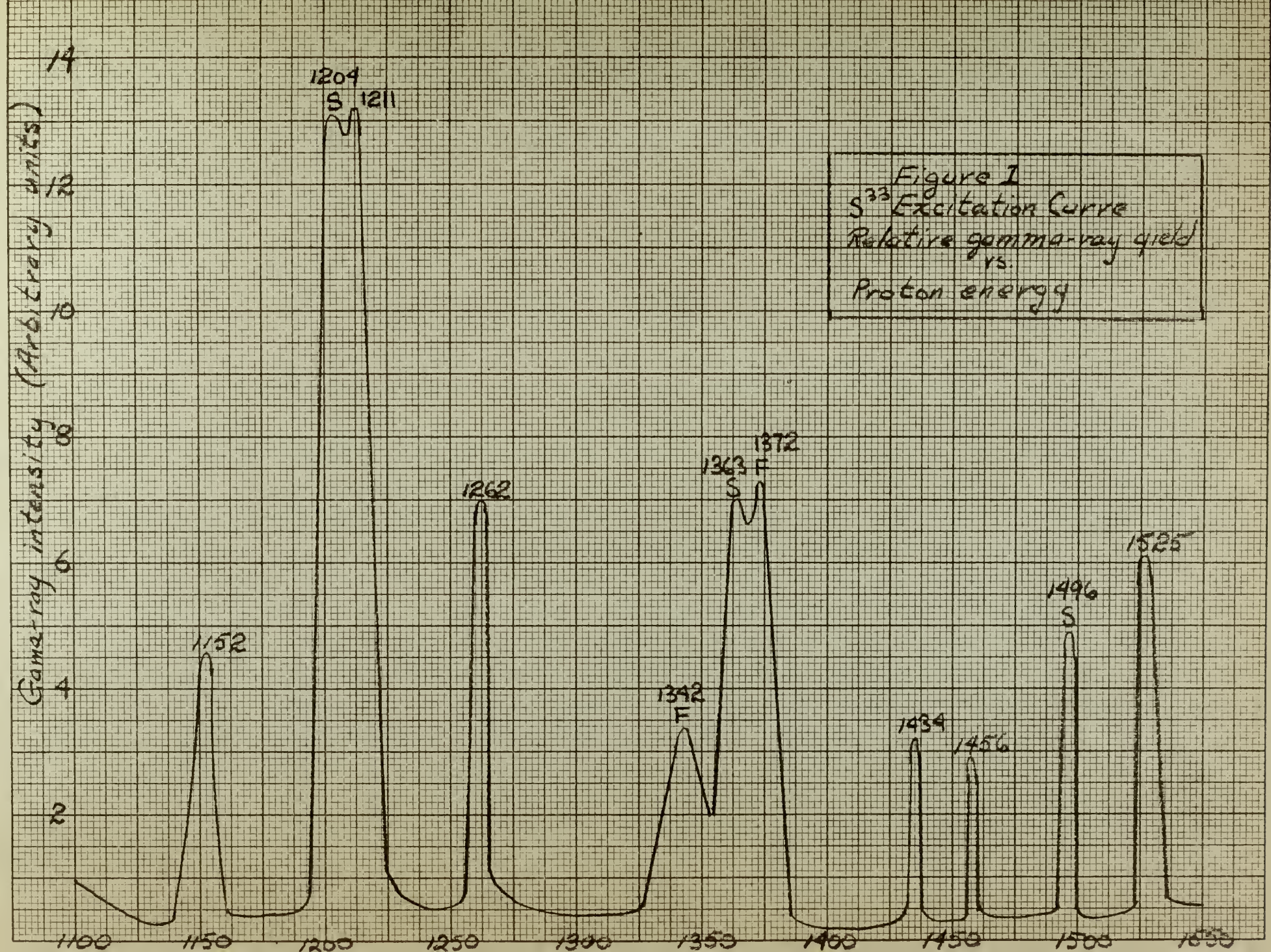
Figure 1
S^{33} Excitation Curve
Relative gamma-ray yield
vs.
Proton energy
Gamma-ray intensity (Arbitrary units)
14
12
10
8
6
4
2
1204
S
1211
1262
1152
1342
F
1363
S
1372
F
1434
1456
1496
S
1525
1100
1150
1200
1250
1300
1350
1400
1450
1500
1550