K PRNC 24 PUERTO RICO NUCLEAR CENTER Simple Experiments that can be done with a NEUTRON SOURCE J OPERATED BY UNIVERSITY OF PUERTO RICO UNDER CONTRACT NO. AT (401-1839 FOR U.S. ATOMIC ENERGY COMMISSION ---Page Break--- Students Method for Determining the Binding Energy of the Deuteron One part of the neutron capture experiment conducted by Marco J. Antonini involved the detection of gamma rays emitted by the capture of neutrons in hydrogen using a Ra-Be neutron source and a Geiger counter as the radiation detector. The experiment suffered from the disadvantage of using a very weak neutron source and an insensitive radiation detecting device. However, more recently, Pringle studied capture gamma rays with a weak Ra-Be neutron source and used a crystal as a more sensitive detector. The fate of the hydrogen atoms in the neutron capture reaction was made by Bell and others during thermal neutron experiments from a reactor. The reported value was 2.23 MeV for the binding energy of the deuteron. A number of illustrative laboratory experiments in neutron capture using a neutron source and commercial instruments have been developed as part of a sequence of experiments constituting a nuclear and reactor physics laboratory. Measuring the binding energy of the deuteron is one of the simple experiments. The procedure and nature of the resulting data will be discussed. The binding energy of a system of particles is the difference between the mass of the individual constituents and the mass of the bound system. The binding energy of the deuteron is B(D) = (M(N) + M(p) - M(D)), where M refers to the atomic mass of the particles. The binding energy of the deuteron can be determined experimentally by the measurement of the energy of the gamma rays which are emitted when thermal neutrons are captured by hydrogen. This is

pouble store the energy approximately equals the The validity of ‘The Q value of the nuclear reaction is given by $Q = (m_{initial} - m_{final})c^2$, where 1 refers to the energy of the particles. Notice that the right-hand side of Eqs (1) and (2) are the same. This means that the binding energy of the deuteron is equal to the Q value of the reaction. That is, B = Q, which is the energy of the release of HP, the energy of the slow neutrons and the energies of excited states with respect to the energy of the emitted gamma-ray photon. It follows from Eq (3) that the Q value of the reaction is approximately equal to the energy of the photon emitted.

---Page Break---

Base Lt Yeap 9.2 Gamma Spectra of Neutrons

It follows that B(Q) = EXPERIMENT AND RESULTS. Figure 1 illustrates the experimental setup. A neutron source is contained in container 1S in a dodecagonal block of plastic 9 in diameter and 10 in high. Measurements of the neutron energy spectrum from this source have shown that there are fast neutrons. Upon interaction with hydrogen atoms in water or in paraffin, the neutrons are moderated to thermal energies. When the neutrons are thus thermal, they can be captured by nuclei with the emission of a gamma-ray photon. The gamma-ray interacts with the NaI scintillator and its energy is recorded.

Figure 2 shows the two gamma rays of 1.37 MeV and 2.76 MeV from Ni. To determine the binding energy of the deuteron, it was decided to use this radioisotope to calibrate the spectrometer. The NaI (NaI(Tl)) was prepared at the PLRUN.C. Swimming Pool Research Reactor. Figure 3 shows a superposition of the gamma-ray spectrum from Ni and the neutron source water. The gain of the spectrometer was varied at about 2.8 MeV during the measurement of the NaI spectrum. The energy of the deuteron peak was found by interpolation between the NaI gamma peaks. The experimental value of the binding energy of H was determined to be 2.21 MeV. The current best value for the binding energy of the deuteron has evolved.

front s ase pilation of mass measurements and reaction dere i822 Mey" Figure 4 illustrates the gamma spectra of the Neutron source in air, water and paraffin. The set en 9.3. Gas aspects Nand puto et in ma ihe, ond one Ray. tid Pah Campy Rr ee SNe Y tveting el, Nc Pape 18 0 sey ---Page Break--- Position of the H* peak which is acen ‘Parafinis characteristic of hydrogen matter, water and containing coretusions: ‘This experiment has been a valuable teaching tool for nuclear and reactor physics laboratory eons (1) The student can calculate the theoretical value of ot Hi @ from the defined binding energy and verify the calculation paper addition to acquaint the student with the theory and operation of gamma-ray spectrometer, {@) 1c demonstrates that an intense beam of thermal neutrons is not necessary to make fairly accurate determination of the binding energy off ‘ACKNOWLEDGMENTS: ‘The writer wishes to thank Dr. ddovar for his cooperation, encouragement, and interest during the preparation of the experiment and Mian Elisa Trabl for preparing the samples of Nat nae! Almo- ---Page Break--- - An Inelastic Neutron Scattering Experiment* te tae ert te - (Received May 14, 1962) . Acne 9 nic by Sut ae a Ya . i Re tm Nees owt Nac Seersaehey eaaahsnis es srenonener ocean oft ng dt oe JN 1935, Auger observed a range increase in the discussed. . tor pe nel ee eee rmorz Be neaminums oF lead were placed near a larger passage through matter, reutones. aay futon sues ands clon! chamber con: alte with sotto eet i be dae een satteted that this aight Ghee in a tater af mca tenner ae 1 © nescoe slow dom by inelte Srons ands mea ee at - stein ir er beng ican Stew vig aces oan . else iles ope te tot ced ae by gamma emision, heatron is ued to excite the struck cles. ‘Re dt pl Wy he tae Sere le he nt ae scien fe of ls Beatin ty oi es taded by Le demonstrating that any Eu ” Sitepuren ye ne - a Sion aon eee ee ea + tea el all ete 8 See ae ry caso Ths cern y bs cent : . as the first establishment of the J (wm)X* vt nat Ao ‘reef ete set Lorry and i pha tae Fg tt

. Stein ch he wren fhe enc ned by Pig In he Siting ery fhe der gs ube en pen Rn nn ses une and meal eae hte tort tration ‘Sonne Sta pt fh eo hh - Site of event ontny Sa nee edt 4 ey Maer incor ryscrauecery. Moments tye cd 2 Nah: tate, and (6) hos . Sein ating om femsaog sac ate a fe pies by mn . Sire nome of te me reece sino Sri ey ipa ert“ ngs seus me of caer apy jel shng eee tp iy anh ge Oe in ma eae, uy i Fenn elegance wie Sea, eee he loan Be - ithe lightest elements is by inelastic scattering. center of mass by the collision. If E, represents Themes ry etc slameate eteyramh he lin, repent tobi oom tig podem gut hese atte cane - cies ymrnmtnerieenes re oe Sm ool sexs SEER Ri oe Bociasate geen - AGS ree fe ett oats Peeters a TERE Garcon 0900 ag, where Mf and m are the mass RETESET fhe mn, ae a oa mas of he a ---Page Break--- INELASTIC NEUTRON SCATTERING we b i. 1. Neato neta seating teraction, feneral, the intial Kinetic energy 7 of the in sing neutron is larger than Ta, the kinetic ‘nergy of the seattered neutron 7: given by TTB, o Ifthe suclear mass is very lange Fe has been found that for neutron energies, excess of 1 MeV, the inelastic seatierng Section approaches the geometrical cross section that is eiamoeR?, where His the raise of the nucleus. Since the radi of atomic mice, except for very low mass number can he eptesetel ReLAX10- AV em, where inthe macs hun ber of the nucleus, the inelastic scattering cose section may be represented approximately by 640.062 A barns, o {follows from the above equation that inorder ‘tw have a large inelastic scattering creme cecton ‘nucle should have a moderate or high mass whumber, EXPERIMENT AND RESULTS ‘The experimental arrangement for the gamma ‘ay measurements is one which employs a rg eomvetry an illustrated Fig. 2. The iron Seatterer which is of the form of an annulus surrounding a sodium iodide crystal, received the neutrons emitted at a small angle from the peutron source. A cone made of para with a base having “borat” dik is ust to abl the 2ysal from direct impact by thermal neutrons 'The crystal and the photomultiplier are mounted in a thin wooden container to shield them from light. The neutron source is placed at about $i from the izon ring. The ring dimensions are approximately 2 in. id. and 4 in. od. A sliding window spectrometer is used to record the gamma-ray photon energy emitted from the excited state of Fe which is produced during the bombardment of iron with fast neutrons. Figure 3 shows the energy distribution spectrum from a Pu-Be neutron source. The fact that the source is very rich in fast neutrons made the use possible in the inelastic scattering experiment. Figure 4 shows the response of the crystal spectrometer with the iron ring present and with the iron ring removed. Iron was used as the scatterer because Fe™ produces a very intense gamma line at about 0.84 MeV. This was very easy to detect with the simple experimental setup used. Both spectra show a visible peak at about 0 MeV due to inelastic scattering in the gamma spectrum of the neutron source, with the distribution of the gamma rays detected by the NaI crystal. The calibration of the spectrometer was performed according to the instruction manual using a C3" source. Conclusions "This simple experiment has been a valuable teaching tool in our classes for the following (1) After a brief introduction to the elementary theory of inelastic scattering, the student is able to perform an experiment and to determine the energy of the intense gamma peak from Fe at 0.84 MeV. (2) The student becomes acquainted with the theory and operation of a gamma-ray spectrometer. (3) It demonstrates that at least one of the lines from the inelastic scattering spectrum of iron can be determined fairly accurately with a Pu-Be neutron source. ACKNOWLEDGMENT 'The writer wishes to express his sincere appreciation to the physics major student Mr. Angel Hermida for his cooperation in the preparation of the experimental setup and for running the spectra.

---Page Break--- A Versatile Experiment Using a Neutron Source and a Tank of Water Eddie Orete Puerto Rico Nuclear Center, College of Agriculture and Mechanical Arts Mayaguez, Puerto Rico Purposes: a- To determine the optimum water depth for neutron moderation. b- To show the effect of neutron reflection in water. c- To obtain the distribution of thermal neutrons in water. INTRODUCTION The experiment described below was worked out in the course of the research undertaken by two graduate students at this college for their master's thesis. S. Pinto Vega, from Colombia, was working on the determination of the optimum thickness of paraffin for the neutron balance between moderation and capture in order to incorporate the data in the design of a high-energy neutron conversion device. H. Plaza, from Puerto Rico, was trying to measure the neutron albedo in water. Since the results were highly interesting in both cases, it was decided to modify the experimental set-up and prepare it for two further experiments in the Nuclear and Reactor Physics Laboratory. The new experiments were designed to establish the precise water depth required for neutron moderation and also the body of water which would be equivalent to an infinite reflector. Furthermore, the data obtained in this experiment can also be used to show the distribution of thermal neutrons in water. EQUIPMENT AND PROCEDURE The experimental set-up is shown in Fig. 1. A neutron source is centered at the bottom of a 43" x 43" x 51" stainless steel tank. A 1/2" diameter and 4" active length BF3 counter is established by the U.S. Atomic Energy Commission as part of the University of Puerto Rico, coupled to an aluminum tube by a Lathapod plastic tube and sealed to secure watertight sealing. The aluminum tube is supported by horizontal bars at the top of the tank and the detector unit can be raised or lowered along a vertical line above the source. With the detector at a fixed distance d from the bottom of the tank, the water level is increased at 1" intervals and the

count rate C recorded at each level until the water is about 10" above the detector. The respective levels are measured by a calibrated water manometer. If the count rate is plotted against the water level, a curve is obtained for the fixed position of the detector. After emptying the tank by means of a pump, the procedure can be repeated by varying the water level so as to obtain a family of curves with water level as a parameter, as shown in Fig. 2. INTERPRETATION OF RESULTS The nature of the experimental curves may be explained qualitatively by taking a particular curve, dividing it into three regions, and considering its course. Fig. 3 shows the three regions: (1) Slowing-down, (2) Absorption, and (3) Reflection. Regions (1) and (2) are similar to those obtained in a transmission experiment when the thickness of the material between detector and source is varied. In order to explain region (1), the following factors must be taken into consideration: The Puche neutron source emits fast neutrons; the count rate of the detector is energy-dependent because it is a L/v absorber; neutron energy is degraded by elastic collision and geometrical effects may be neglected. As the water level rises, the energy spectrum of the neutrons escaping toward the detector will vary, depending on the number of collisions with H nuclei, and the neutrons within the energy threshold of the detector will be counted. With further rises in the water level, the neutrons escaping toward the detector become practically thermal and consequently the count rate will increase. When a water level is reached at which the neutrons are thermalized, however, the curve starts bending toward a maximum due to absorption. At point B, where there is a state of balance between moderation and capture, the maximum count rate is obtained: Curve Ab is called the slowing-down curve since at this point thermalization is at its optimum. Raising the water level beyond this point will increase neutron absorption with a consequent decrease in the count rate.

number of thermal neutrons escaping toward the detector. Curve BC is a typical attenuation curve due to neutron absorptions. At water level fic, backscattering of neutrons to the detector will begin while some neutrons will escape and be absorbed. Consequent rises in the water level will increase the neutron count due to collision and reflection until a steady rate is obtained. Curve ODE represents the reflection or backscattering region. At this stage of the experiment, purposes (a) and (b) have been accomplished, viz: The optimum water depth for neutron thermalization is about 5", independently of the position of the detector. Above a level higher than 4" above the detector, the count rate remains constant; accordingly, this level can be considered equivalent to an infinite amount of water above the detector. In order to accomplish purpose (c) of the experiment, the data from Fig. 2 can be replotted to show the relationship between G and d, H being kept constant. If this is done for $d > 4$, the relationship between the count rate and the distance of the detector from the bottom for a filled tank of infinite size is obtained. If r is the distance from the source to the detector, we find that $r = d - 2$ since the source is 2" high. If a semi-log plot of G against r is made, results similar to those shown in Fig. 4 are obtained. Here the curve represents the distribution of thermal neutrons in water. Since if x is large the curve is a straight line, this relationship can be expressed by the function $G = A * e^{(-r/L)}$ where A is the attenuation length. From the folding value of the count rate, an attenuation length of 4.4" is obtained, or r/Q conclusions. The above experiment is of great practical value for the following: after an introduction to the theory of the neutron slowing-down and reflection properties of moderating media, the student should perform the experiment so as to determine that the optimum depth of water for neutron thermalization is about 5", and that 4M of water.

are equivalent to an infinite body of water above the detector. Also, the student will be made to realize that the reason why the critical mass of a reactor can be reduced by surrounding the reactor core with reflectors is the consequent decrease in the probability of neutron leakage. From the thermal distribution of neutrons in water, the student will establish that starting at 6" from the source, the attenuation length is 4.4. This aspect of the experiment is very important in connection with thermal neutron shielding design. The simplicity and relatively low cost of the equipment needed makes the experiment feasible in any laboratory possessing a neutron source and neutron counting accessories, that is to say, it can be carried out in practically any modern physics laboratory at college or university level. ---Page Break--- FIG. ---Page Break--- a tb 2 ---Page Break--- ---Page Break--- beep 2 3 ~ wd FIG.4 1o# ---Page Break---