Die Wirkungsquerschnittsformel wurde mit Erfolg auf Spallationsprodukte, erzeugt bei Energien von 0,17 sowie 2 und 6 GeV, angewandt. Die Genauigkeit, mit der die Parameter bestimmt werden konnten, verlangt, daß die experimentellen Werte innerhalb eines Faktors 2 mit den berechneten übereinstimmen. Nur bei den Neonisotopen ist diese Forderung nicht erfüllt. Dies zeigt, daß bereits von der Masse 20 an (zu kleineren Werten hin) der sogenannte Fragmentationsprozeß eine Rolle spielt, d. h. daß bei diesen Energien Kernbruchstücke der Masse 20 vom Targetkern abgesprengt werden können.

Zusammenfassung

Für die Edelgasisotope, die unterhalb der Targetmassenzahl liegen, und für Tritium konnten Wirkungsquerschnitte mit einer Genauigkeit von etwa 20% bestimmt werden. Die Ergebnisse zeigen gegen-

über Bestrahlungen bei niedriger Energie keine wesentlichen Besonderheiten. Die Wirkungsquerschnitte für die leichten Verdampfungsteilchen zeigen abnehmende Tendenz. Innerhalb der erwarteten Genauigkeit stimmen die Ergebnisse für die Argonisotope mit den berechneten Werten nach RUDSTAMS Formel gut überein. Es ist auffallend, daß die bei niedriger Energie gemessene höhere Produktion von He^3 in Eisen immer noch vorhanden ist. Im Gegensatz dazu ist das He^3 /Tritium-Verhältnis wesentlich kleiner als 1 für Kupfer. Es wäre von Interesse, das He^3 /Tritium-Verhältnis auch bei Nachbar-elementen des Eisens zu bestimmen.

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Ne in some Stone Meteorites*

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Ne^{20} , Ne^{21} and Ne^{22} has been measured in several stone meteorites. Good agreement with other cosmic ray produced rare gas isotopes was obtained. No indication of primeval neon was found in the chondrites, but one urelite showed excess Ne^{20} .

Ne in meteorites is produced by cosmic ray induced spallation, or is trapped gas of the atmosphere in which the meteorite was originally formed. It can therefore give information on the cosmic radiation and cosmic ray age of the meteorite and of the primeval atmosphere of the parent body of the meteorite.

Extensive work has already been done on iron meteorites^{1, 2}, less on stones. GERLING and LEVSKII³ measured He, Ne and A in 9 stone meteorites, however, some of their results show relatively large errors. REYNOLDS and LIPSON⁴ published data on the rare gas content of Nuevo Laredo and recently GOEBELS et al.⁵ of Ramsdorf.

Samples used

Table 1 contains a short description of the measured meteorites.

Experimental technique

The crushed meteorite sample was reacted in a nickel crucible with borax as flux for 2 h at 1250 °C. To prevent gas discharges, induced by the induction heater, about 10 mm Hg of triple distilled CO_2 were added. After the crucible had cooled down below 300 °C the evolved rare gases were cleaned with titanium (about 8 g Ti-foil, .00025" thick). Using charcoal, A was separated from the Ne and He, and the latter were then toeplered into a sample tube. Mercury cut-offs were

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³ E. K. GERLING and L. K. LEVSKII, Dokl. Akad. Nauk SSSR 107, 555 [1956].

⁴ J. H. REYNOLDS and J. I. LIPSON, Geochim. Cosmochim. Acta 12, 330 [1957].

⁵ K. GOEBEL, P. SCHMIDLIN and J. ZÄHRINGER, Z. Naturforsch. 14 a, 996 [1959].

Meteorite	Classification	Total recovered mass	Date of fall	Origin of sample
Holbrook	Cryst. Sph. hyp. chond.	220 kg	July 19, 1912	Aliquot of crushed sample used by GEISS and HESS ⁷ and EBERHARDT and HESS ⁸
Richardton	Veined Sph. br. chond.	90 kg	June 30, 1918	
St. Michel	Wh. hyp. chond.	17 kg	July 12, 1910	
Bjurböle	Sph. hyp. chond.	330 kg	March 12, 1899	
Furnas County	Aubrite	1000 kg	Feb. 18, 1948	US Nat. Mus. Washington
Olivine Brenham	Pallasite	> 1000 kg	found 1882	
Goalpara	Ureilite	3 kg	found 1868	
Novo Urei	Ureilite	2 kg	Sept. 4, 1886	

Table 1. Description of meteorites. Data from PRIOR and HEY⁶.

used in the extraction line and the extraction vessel was opened with a flange and metal gasket. The mercury cut-offs and Toeplerpump were backed with CO₂. The meteorite sample and extraction jacket were freed of adsorbed gases by passing steam through the double wall extraction jacket.

Extensive tests showed completeness of the extraction. All samples were reheated a second time. No Ne²¹ could be detected in the reruns ($< \frac{1}{2}\%$ of total Ne²¹). Some extractions were made by melting the meteorite in a graphite crucible at $\sim 1550^\circ\text{C}$. The isotopic composition and total amounts agreed with the borax-extractions.

Besides the reheating of the sample, frequent blank runs were made. Small amounts of atmospheric Ne were found, due to inleakage through the cold Pyrex tubing. Therefore all isotopic composition runs were repeated, varying the sample size (.3 to 2 g), and therefore the blank correction by at least a factor two. Good agreement between the individual runs was always obtained.

The amounts of neon were measured by isotopic dilution. Air neon was used as spike and prepared by the usual methods⁹. Intercalibration with Dr. P. SIGNER from the University of Minnesota showed absolute agreement within 5%. The isotopic composition was measured on a small trochoidal massspectrometer¹⁰. The machine was operated static, and calibrated by running air-neon.

Table 2 contains the result. The blank correction has been applied. The Ne²¹ concentrations are accurate to 5% absolute and 3% relative, the Ne²⁰/Ne²² ratios to 2% and the Ne²¹/Ne²² to 1%. The results of Goalpara and Novo Urei are from a single run and the Ne²¹ concentration is estimated from the ion beam intensity. Therefore the errors are larger.

Meteorite	$\frac{\text{Ne}^{21}}{\text{Ne}^{22}} \cdot 10^{-2}$	$\frac{\text{Ne}^{20}}{\text{Ne}^{22}} \cdot 10^{-2}$	$\text{Ne}^{21} \cdot 10^{-8}$ cc STP/g
Chondrites			
Holbrook	95.5 ± 1	92.0 ± 2	$6.70 \pm .35$
Richardton	95.5 ± 1	91.5 ± 2	$9.50 \pm .50$
St. Michel	95.0 ± 1	92.0 ± 2	$8.20 \pm .40$
Bjurböle	93.5 ± 1	92.5 ± 2	$4.45 \pm .25$
Achondrites			
Furnas County	93.5 ± 1	90.0 ± 2	58.5 ± 2.5
Goalpara	87.5 ± 2	98 ± 5	$8.8 \pm .9$
Novo Urei	90.0 ± 2	129 ± 5	$2.7 \pm .3$
Pallasite			
Olivine Brenham	106.0 ± 1	94.0 ± 2	36.5 ± 2.0
Atmospheric neon	2.9	1030	—

Table 2. Results. All errors are absolute. The Ne²¹ concentrations are accurate relative to 3% (except Goalpara and Novo Urei).

Discussion of results

Ne²¹ has very low cosmic and terrestrial abundance relative to Ne²⁰ ($\text{Ne}^{21}/\text{Ne}^{20} = 2.8 \cdot 10^{-3}$ in air). Therefore, all Ne²¹ in the measured meteorites is made by spallation. The same is true of He³, but not necessarily⁷ of A³⁸. Table 3 shows the He³/Ne²¹, He³/A³⁸ and Ne²¹/A³⁸ ratios. These ratios depend on the chemical composition of the meteorite. He³ is made from all the elements, Ne²¹ mainly from Na, Mg, Al and Si, A³⁸ mainly from Ca, K, Fe and Ni. Not much experimental data on the corresponding cross-sections is available at the present time.

Chondrites are generally very constant in chem-

⁶ G. T. PRIOR and M. H. HEY, Catalogue of Meteorites, London 1953.

⁷ J. GEISS and D. C. HESS, Astrophys. J. **127**, 224 [1958].

⁸ P. EBERHARDT and D. C. HESS, Astrophys. J. **131**, 38 [1960].

⁹ G. J. WASSERBURG and R. J. HAYDEN, Geochim. Cosmochim. Acta **7**, 51 [1955].

¹⁰ P. EBERHARDT, Helv. Phys. Acta **33**, 588 [1960].

Meteorite	He ³ /Ne ²¹	He ³ /A ³⁸	Ne ²¹ /A ³⁸
Holbrook	4.1	26	6.3
Richardton	3.5	29	8.2
St. Michel	3.8	30	7.7
Bjurböle	3.7	14	3.6
Furnas County	3.8	115	30
Olivine Brenham	2.9	130	45

Table 3. Ratio of spallation produced rare gases. Data from: A³⁸ GEISS and HESS⁷; He³ EBERHARDT and HESS⁸; Ne²¹ this paper.

ical composition. A comparison of the compositions of Holbrook, Richardton, St. Michel and Bjurböle shows, that the macroscopic cross sections for the production of He³, Ne²¹ and A³⁸ should not vary by more than 10%. This is in excellent agreement with the measured He³/Ne²¹ ratios which agree within 8% (average 3.8). "Cosmic ray ages" deduced from Ne²¹ therefore agree with the He³ ages. Any diffusion loss of He³ seems very unlikely as one would certainly expect variations from one meteorite to another. The average Ne²¹ production rate in chondrites is $2.5 \cdot 10^{-15}$ cc STP g⁻¹ year⁻¹ using the He³-ages of EBERHARDT and HESS⁸.

Furnas County and the olivine of Brenham have higher Mg contents than the chondrites but are lower in Na and Al. The He³/Ne²¹ ratio = 3.8 in Furnas County shows, that the macroscopic Ne²¹ production cross-section is about the same as in a chondrite, and the influence of the different chemical composition cancels out. Brenham has a lower He³/Ne²¹ ratio. This may be due to the high Mg content. The Ne²¹/Ne²² ratio is much higher than in the other meteorites, indicating that the reaction Mg²⁴ (p, α) played an important role. Novo Urei and Goalpara have a chemical composition similar to Furnas County. To calculate their Ne²¹ "cosmic ray age" the production rate for chondrites can be used without introducing an error of more than 30%. We calculate 35 my for Goalpara and 10 my for Novo Urei.

¹¹ P. EBERHARDT and J. GEISS, Z. Naturforschg. 15a, 547 [1960].

GERLING and LEVSKII³ found in the achondrite Pesyanoe large amounts of He⁴, Ne²⁰, Ne²²; A³⁶, A³⁸ with about atmospheric isotopic composition. They concluded, that these were remnants of the primeval atmosphere in which the meteorite was formed. Some of the chondrites investigated by GEISS and HESS⁷ have high A³⁶/A³⁸ ratios. They gave two possible explanations: either formation of A³⁶ by thermal neutrons from Cl³⁵ or trapped primeval gas. They had excluded atmospheric contamination by careful experimental techniques. The low He³/A³⁸ ratio of Bjurböle favours the second explanation⁸. Furthermore, the required thermal neutron fluxes are high and could hardly be provided by cosmic ray interactions.

No indication of excess Ne²⁰ was found in Bjurböle or in any other chondrite. Holbrook has the lowest A³⁶/A³⁸ ratio of all 4 chondrites. Taking its Ne²⁰/Ne²¹ ratio as that of spallation produced neon, we can calculate limits for the excess non spallation Ne²⁰ of the other 3 chondrites (see Table 4). EBERHARDT and GEISS¹¹ have shown, that these limits do not exclude the possibility that part of the A³⁶ is primeval.

Meteorite	Non spallation Ne ²⁰ · 10 ⁻⁹ cc STP/g
Richardton	≤ 5
St. Michel	≤ 5
Bjurböle	≤ 4

Table 4.
Limits of non
spallation Ne²⁰.

Novo Urei shows a high Ne²⁰/Ne²¹ ratio. This could certainly be interpreted as primeval gas. On the other hand, both urelites are very porous stones and give off larger amounts of gas during the initial pumping and extraction than the other meteorites. We cannot exclude the possibility of adsorbed atmospheric neon in this particular meteorite.

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