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Report on noble gas isotopic compositions of the 1E and 2E samples: An example of noble gas analyses for small sample sizes

By

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Abstract: Isotopic compositions and concentrations of noble gases were analyses for 1E and 2E samples. Two noble gas mass spectrometry systems were used for the analyses; MS-II for total melting and stepwise heating experiments on samples weighing 8–32 mg, and MS-III for laser heating using single or several grains weighing 3–40 μg. Our data suggest that the sample 1E has noble gases similar to those for type 6 ordinary chondrites, while noble gases in 2E resemble those of carbonaceous chondrite Allende (CV3). Based on the present results we can conclude; 1) for ordinary chondritic materials several mg of sample is enough to measure all noble gas isotopes, 2) for surface materials of asteroids which would contain large amounts of implanted solar noble gases, the analytical technique using laser heating is applicable to samples weighing several μ g or less, 3) noble gas isotopic compositions obtained by the technique of single grain analysis can separate grains of different meteoroids impacted asteroidal surface, and 4) histories of exposure to cosmic-rays as well as impact degassing for each grain can provide detailed erosion process occurring on the asteroidal surface.

1. SYSTEMS FOR NOBLE GAS MASS SPECTROMETRY USED IN THIS STUDY

Two noble gas mass spectrometer systems MS-II and MS-III at the Laboratory for Earthquake Chemistry, University of Tokyo have been used for measurement of concentrations and isotopic compositions of noble gases. As mass spectrometers of the MS-II and MS-III, which were originally VG5400 (VG Isotech), have been specially modified in our laboratory, we call them as modified-VG5400. Outlines of the systems MS-II and MS-III for noble gas mass spectrometry are schematically drawn in Figs. 1 and 2, respectively. The MS-II is used for analysis

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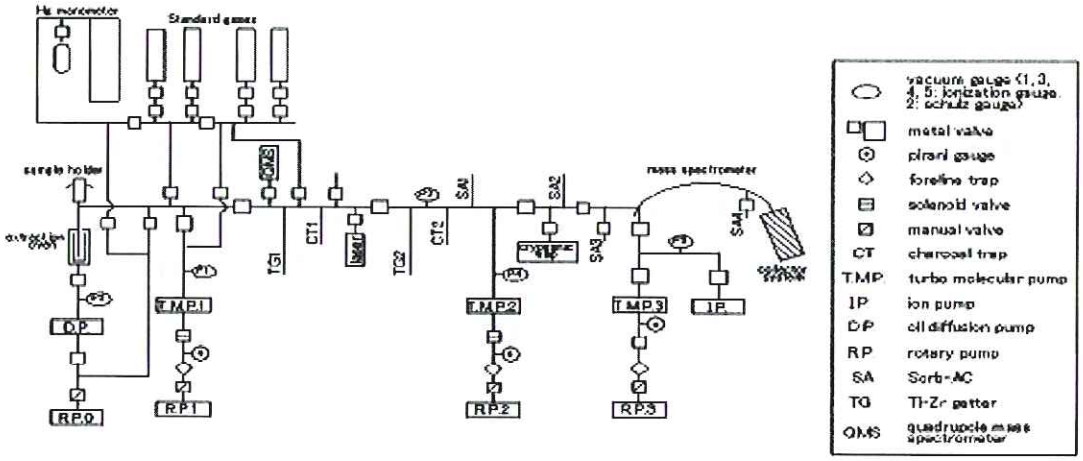

Fig. 1:

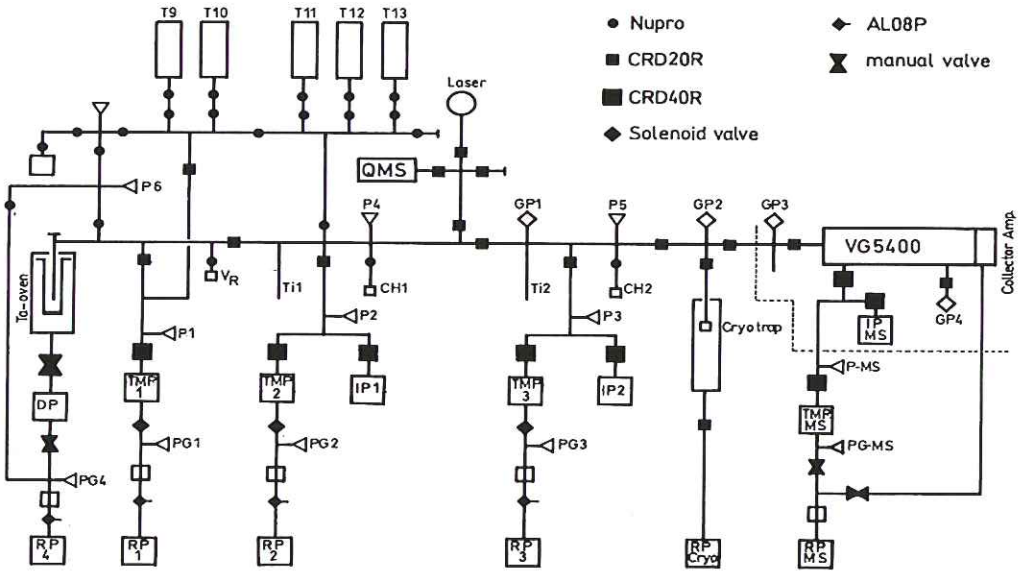

Fig. 2:

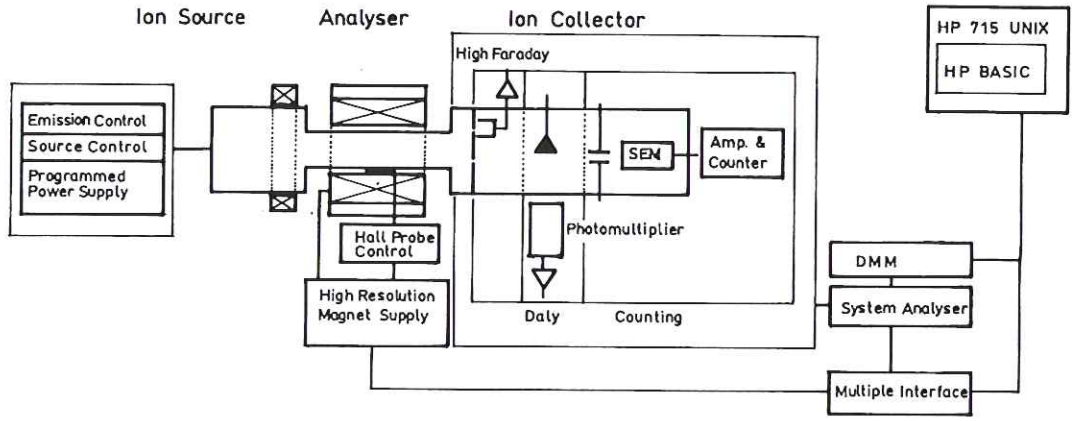

Fig. 3:

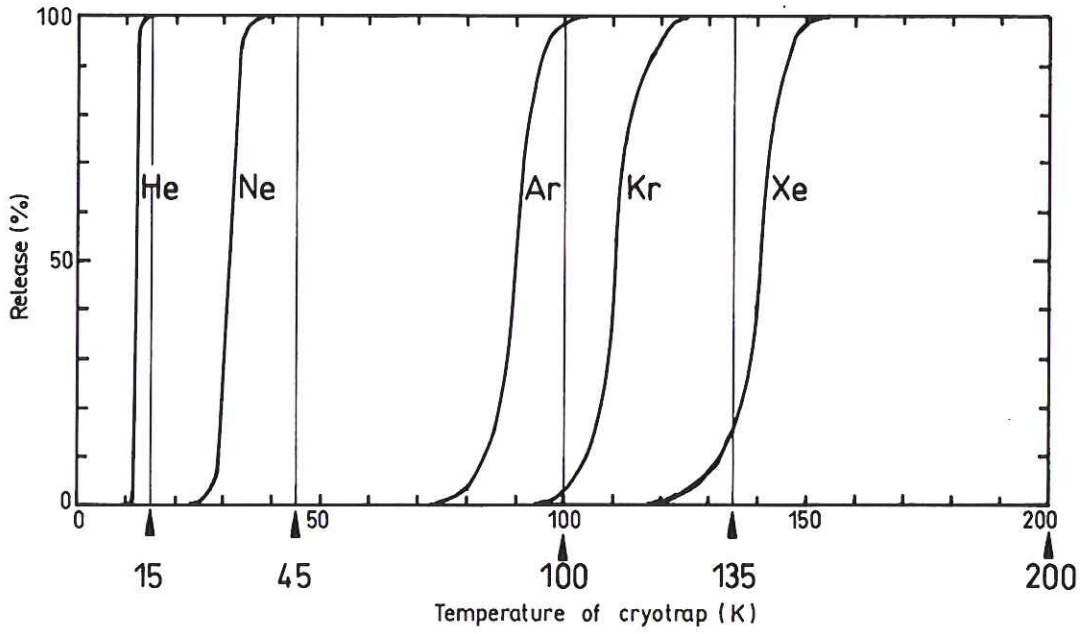

Fig. 4:

of relatively large extraterrestrial samples such as meteorites (>mg), while the MS-III is for smaller extraterrestrial materials such as cosmic dust grains and micrometeorites (< 10 μg) and terrestrial rock or gas samples.

Since both the systems are principally the same, we describe the MS-III in detail using Fig. 2. The system is composed of several parts, i.e., a noble gas extraction furnace (Ta-

oven), Ti-Zr getters (Ti1 and Ti2) and SAES getters (GP1 - GP4) for purification of noble gases, charcoal traps (CH1 and CH2) and a cryogenic trap (Cryo-trap) for separation among noble gas elements, standard gas reservoirs (T9 - T13), a ultrahigh vacuum pumping system using turbomolecular pumps (TMP1 -TMP3) and ion pumps (IP1 - IP2), and the modified-VG5400 mass spectrometer. All the parts are maintained at pressure lower than 1×10^{-9} Torr. Peak scanning, data acquisition, and calculation of isotopic ratios using the modified-VG5400 are performed by a computer program developed in our laboratory. Block diagram of the computer controlled system is shown in Fig. 3. Three different types of ion collector of the mass spectrometer have been improved. Detection limit of Xe isotope is less than 1×10^{-16}cm^3 STP using the ion counting system.

For separation of noble gas elements, the Cryo-trap is principally used in this work. Fig. 4 shows release patterns of each noble gas element. Noble gases trapped on the Cryo-trap at low temperature were successively released by increasing temperature of the trap, and were measured on the mass spectrometer separately.

2. ANALYTICAL PROCEDURES AND RESULTS

2.1 Total melt and stepwise heating noble gas extraction using MS-II

Samples weighing $8 \sim 32$ mg were wrapped in Al-foil (8 μm thick) and installed in a glass sample holder on the extraction furnace. The extraction and purification line were heated at about 250°C for almost a day, and the samples at 150°C to degas adsorbed atmospheric noble gas contamination. During the heating procedure, a Mo crucible of the extraction furnace was repeatedly heated at about 1900°C for degassing. Noble gas extraction by total melting was performed on small samples weighing 9.0 mg (1E) and 8.2 mg (2E). Sample was dropped into the crucible and heated at 1750°C for 10 minutes. Released noble gases were purified by exposing them on Ti-Zr getters and SAES getters, and separated into four fractions, i.e., He-Ne, Ar, Kr, and Xe, using a charcoal trap (CH1) and the Cryo-trap, and then introduced into the mass spectrometer for isotope measurements. Sensitivities and mass discrimination correction factors of the mass spectrometer were determined by measurements of known amounts of atmospheric noble gases and^3 He/^{4}He standard gas. Blank levels of noble gases were also measured.

Procedures for stepwise heating noble gas extraction were principally the same as those applied for total melting. Heating temperature of the sample dropped in the crucible was increased stepwisely, and noble gases released at each temperature were purified and measured with the same procedures for total melt experiment. The temperatures employed in this work were 700, 900, 1100, 1300 and 1700°C.

Doubly charged ^{40}Ar and CO_2 interfering ^{20}Ne and ^{22}Ne ions, respectively, were monitored by measuring single charged ^{40}Ar and CO_2 before and after the Ne isotopic analysis. Ne isotopic ratios were calculated by correcting for the doubly charged ions using empirically determined $^{40}Ar^{2+}/^{40}Ar^{+}$and CO_2^{2+}/CO_2^{+} ratios. Experimental uncertainties for concentrations are estimated to be 5–10%, and the errors cited for isotopic ratios are statistical 1σ.

Noble gas concentrations and isotopic ratios by total melting and stepwise heating experiments are presented in Tables 1–4. In Table 1, absolute amounts and isotopic ratios of noble gases released from both blank runs and samples are summarized. Except for ^{4}He, blank levels are less than 10% of the gas amounts from samples, and are negligible in most cases. The almost constant blank level of ^{4}He (5×10^{-10} cm^{3}STP) is due to atmospheric He permeation through glass wall of the sample holder. Blank level of ^{4}He due to the atmospheric He be-

Table 1: Absolute amounts and isotopic ratios of noble gases released from blank runs, and total melt and stepwise heating of samples.

Sample	Weight mg	Temp.	^{3}He	^{4}He	^{3}He/^{4}He	error	^{20}Ne	^{20}Ne/^{22}Ne	error	^{21}Ne/^{22}Ne	error	^{36}Ar	^{40}Ar	^{38}Ar/^{36}Ar	error	^{40}Ar/^{36}Ar	error	^{84}Kr	^{132}Xe
			10^{-9}cc				10^{-9}cc					10^{-9}cc						10^{-12}cc	
Total melt at 1750 °C																			
Blank		1750	0.0001	0.5	0.000198	0.000039	0.0012	7.729	0.318	0.160	0.029	0.003	0.9	0.192	0.002	286.6	2.1	0.10	0.05
1E	9.0	1750	0.9642	15.5	0.062209	0.000231	0.2940	0.900	0.003	0.919	0.003	0.119	43.4	0.360	0.002	365.0	1.5	3.36	1.27
2E	8.2	1750	0.7142	255.0	0.002801	0.000010	0.5440	2.255	0.004	0.763	0.002	1.152	171.0	0.198	0.001	148.4	0.5	16.70	13.50
Stepwise heating																			
Blank		700	0.0001	0.4	0.00032	0.00003	0.0011	7.270	0.440	0.240	0.020	0.002	0.5	0.192	0.002	277.1	1.7	0.03	0.01
Blank		1100	0.0001	0.5	0.00026	0.00003	0.0016	8.612	0.512	0.085	0.025	0.002	0.5	0.195	0.003	276.8	1.5	0.07	0.05
Blank		1700	0.0001	0.5	0.00026	0.00003	0.0016	8.612	0.512	0.085	0.025	0.003	0.9	0.192	0.002	286.6	2.1	0.09	0.05
1E	30.9	700	2.2787	36.1	0.06312	0.00024	0.1220	0.952	0.006	0.905	0.002	0.060	50.9	0.380	0.003	841.6	11.6	2.73	0.83
1E		900	0.7567	10.4	0.07276	0.00035	0.1220	0.839	0.006	0.909	0.003	0.037	25.7	0.308	0.002	698.0	8.1	1.31	0.50
1E		1100	0.2253	5.3	0.04250	0.00014	0.2190	0.857	0.003	0.940	0.003	0.065	20.6	0.317	0.002	315.6	1.1	2.12	0.80
1E		1300	0.0195	1.3	0.01466	0.00012	0.3700	0.842	0.002	0.913	0.002	0.101	10.7	0.651	0.003	105.9	0.3	2.43	1.05
1E		1700	0.0032	1.1	0.00287	0.00004	0.1270	0.867	0.005	0.946	0.003	0.032	3.6	0.332	0.002	112.1	0.3	0.95	0.64
2E	32.0	700	1.8332	587.0	0.00312	0.00001	0.5000	2.326	0.005	0.714	0.002	0.038	37.2	0.173	0.002	980.9	15.7	15.00	5.74
2E		900	0.4407	225.0	0.00196	0.00001	0.7090	3.999	0.006	0.553	0.001	0.229	57.0	0.198	0.001	249.1	0.8	4.15	2.85
2E		1100	0.4261	144.0	0.00296	0.00004	0.4800	1.856	0.009	0.830	0.005	1.994	160.0	0.201	0.001	80.3	0.2	27.00	19.90
2E		1300	0.0549	21.4	0.00257	0.00002	0.3220	1.657	0.004	0.856	0.003	1.848	66.3	0.202	0.001	35.9	0.1	22.60	17.90
2E		1700	0.0096	2.6	0.00369	0.00002	0.0685	0.981	0.012	0.923	0.004	0.095	8.8	0.211	0.001	92.5	0.3	1.67	1.38

Table 2: Concentrations and isotopic ratios measured by total melting and stepwise heating.

Sample	Weight	Temp.	^{3}He	^{4}He	^{3}He/^{4}He	^{20}Ne	^{21}Ne	^{22}Ne	^{20}Ne/^{22}Ne	^{21}Ne/^{22}Ne	^{36}Ar	^{38}Ar	^{40}Ar	^{38}Ar/^{36}Ar	^{40}Ar/^{36}Ar	^{84}Kr	^{132}Xe
	mg		10^{-9}cc/g			10^{-9}cc/g					10^{-9}cc/g					10^{-12}cc/g	
1E	30.9	700	73.74	1153	0.06393	3.90	3.75	4.14	0.9412	0.9057	1.894	0.731	1630	0.3856	860.4	86.1	25.2
(Step heat)					± 24				± 61	± 21				± 29	± 12.2		
		900	24.48	322	0.07611	3.90	4.27	4.70	0.8291	0.9097	1.129	0.355	814	0.3148	721.5	40.1	14.5
					± 37				± 60	± 28				± 19	± 8.8		
		1100	7.29	157	0.04650	7.04	7.77	8.26	0.8513	0.9407	2.049	0.657	649	0.3206	316.8	66.3	24.2
					± 15				± 31	± 34				± 19	± 1.2		
		1300	0.63	28	0.02225	11.92	12.98	14.21	0.8390	0.9134	3.207	2.115	329	0.6594	102.5	76.4	32.4
					± 19				± 16	± 16				± 31	± 0.3		
		1700	0.10	21	0.00475	4.06	4.49	4.74	0.8566	0.9473	0.968	0.330	98	0.3414	101.4	28.5	19.1
					± 6				± 52	± 26				± 21	± 0.3		
		Total	106.2	1681	0.06321	30.8	33.3	36.0	0.8546	0.9227	9.25	4.19	3520	0.4529	380.7	297	115
1E	9.0	1750	107.1	1667	0.06425	31.3	33.3	36.1	0.8677	0.9225	12.9	4.69	4726	0.3646	367.1	362	135
(Total melt)					± 24				± 33	± 27				± 23	± 1.5		
2E	32.0	700	57.3	18329	0.003125	15.57	4.79	6.71	2.3204	0.7141	1.124	0.193	1145.7	0.1719	1019.0	466.6	177.8
(Step heat)					± 8				± 53	± 20				± 18	± 17.2		
		900	13.8	7017	0.001962	22.11	3.06	5.53	3.9941	0.5532	7.091	1.407	1764.4	0.1984	248.8	127.5	87.5
					± 14				± 63	± 12				± 11	± 0.8		
		1100	13.3	4486	0.002968	14.95	6.71	8.07	1.8514	0.8304	62.244	12.481	4983.2	0.2005	80.1	841.6	620.3
					± 43				± 87	± 47				± 11	± 0.2		
		1300	1.7	654	0.002618	10.01	5.20	6.07	1.6503	0.8566	57.705	11.658	2055.0	0.2020	35.6	704.1	557.8
					± 21				± 35	± 26				± 11	± 0.1		
		1700	0.3	67	0.004432	2.09	2.01	2.18	0.9600	0.9248	2.896	0.613	256.6	0.2115	88.6	50.0	41.6
					± 27				± 116	± 40				± 12	± 0.3		
		Total	86.4	30553	0.002827	64.7	21.8	28.6	2.2661	0.7622	131.1	26.35	10205	0.2011	77.9	2190	1485
2E	8.2	1750	87.1	31037	0.002806	64.9	22.4	29.2	2.2193	0.7672	140.2	27.80	20749	0.1984	148.0	2025	1640
(Total melt)					± 10				± 35	± 18				± 12	± 0.5		

Table 3: Kr isotopic ratios by total melt and stepwise heating.

Sample	Temp.	$^{78}Kr/^{84}Kr$		$^{80}Kr/^{84}Kr$		$^{82}Kr/^{84}Kr$		$^{83}Kr/^{84}Kr$		$^{86}Kr/^{84}Kr$
1E	700	0.00625		0.0415		0.2011		0.2021		0.3046
(Step heat)		± 28	±	5	±	41	±	20	±	30
	900	0.00722		0.0452		0.2092		0.2130		0.3019
		± 60	±	9	±	34	±	47	±	68
	1100	0.00654		0.0433		0.2044		0.2045		0.3026
		± 41	±	10	±	22	±	49	±	17
	1300	0.00666		0.0429		0.2031		0.2046		0.3015
		± 29	±	5	±	24	±	34	±	32
	1700	0.00624		0.0416		0.2054		0.2014		0.3070
		± 20	±	10	±	42	±	45	±	67
1E	1750	0.00625		0.0418		0.2035		0.2025		0.3031
(Total melt)		± 13	±	6	±	34	±	19	±	17
2E	700	0.00605		0.0536		0.2043		0.2027		0.3075
(Step heat)		± 16	±	8	±	36	±	17	±	15
	900	0.00577		0.0826		0.2107		0.2006		0.3118
		± 25	±	20	±	29	±	20	±	30
	1100	0.00610		0.0565		0.2085		0.2025		0.3102
		± 10	±	5	±	10	±	8	±	17
	1300	0.00610		0.0460		0.2038		0.2029		0.3102
		± 12	±	4	±	14	±	8	±	10
	1700	0.00625		0.0510		0.2065		0.2037		0.3085
		± 33	±	17	±	40	±	25	±	41
2E	1750	0.00592		0.0532		0.2061		0.2023		0.3085
(Total melt)		± 15	±	4	±	4	±	11	±	16

comes comparable to the He abundance from samples in high temperature fractions of stepwise heating, e.g., 1300 and 1700°C of the 1E sample.

Isotopic ratios and concentrations of noble gases determined by total melting and stepwise heating show good agreements among them as shown in Table 2. Exceptions are the differences between the ^{40}Ar concentrations. The disagreements are likely due to atmospheric Ar contamination adsorbed on the samples or due to heterogeneous concentration of potassium in these samples.

2.2 Laser heating noble gas extraction using MS-III

We tried to measure noble gases in single or several grains picked up from the 1E and 2E samples. Numbers of grains and weights are listed in Table 5. Because of the low concentrations of noble gases in 1E (Table 2), 3∼7 grains with total weights of 17∼41 μg were heated together. For 2E with relatively high concentrations of noble gases, we challenged to single grain analysis with weight of about 3 μg. The samples were set in a sample holder made of Ta and stainless steel with narrow holes of 2 mm in diameter and 5 mm deep. The sample holder was installed in an ultrahigh vacuum chamber for laser heating, and then preheated at 150°C for 5 days to eliminate atmospheric contamination. Noble gases were extracted by heating with slightly defocused Nd-YAG CW laser beam. Output power of the laser gradually increased to melt the grain(s), which can be observed on a CRT monitor displayed through a CCD camera and a microscope system. Mass spectrometry of the extracted noble gases were almost the

Table 4: Xe isotopic ratios by total melt and stepwise heating.

Sample	Temp.	$^{124}Xe/^{132}Xe$		$^{126}Xe/^{132}Xe$		$^{128}Xe/^{132}Xe$		$^{129}Xe/^{132}Xe$		$^{130}Xe/^{132}Xe$		$^{131}Xe/^{132}Xe$		$^{134}Xe/^{132}Xe$		$^{136}Xe/^{132}Xe$
1E	700	0.00374		0.00343		0.0749		1.036		0.1537		0.801		0.3830		0.3309
(Step heat)		± 36	±	41	±	22	±	18	±	21	±	10	±	59	±	46
	900	0.00425		0.00397		0.0739		1.087		0.1523		0.799		0.3876		0.3214
		± 61	±	33	±	14	±	25	±	57	±	19	±	125	±	90
	1100	0.00462		0.00406		0.0772		1.186		0.1549		0.803		0.3883		0.3309
		± 33	±	40	±	25	±	14	±	31	±	15	±	67	±	80
	1300	0.00434		0.00412		0.0775		1.187		0.1557		0.797		0.3905		0.3315
		± 32	±	33	±	27	±	12	±	26	±	12	±	62	±	44
	1700	0.00467		0.00366		0.0783		1.101		0.1583		0.807		0.3821		0.3237
		± 53	±	26	±	30	±	19	±	22	±	26	±	83	±	75
1E	1750	0.00416		0.00402		0.0754		1.110		0.1541		0.793		0.3906		0.3306
(Total melt)		± 14	±	28	±	18	±	9	±	30	±	14	±	57	±	41
2E	700	0.00421		0.00375		0.0771		1.157		0.1549		0.805		0.4126		0.3658
(Step heat)		± 22	±	13	±	8	±	9	±	14	±	5	±	32	±	25
	900	0.00524		0.00435		0.0840		2.294		0.1558		0.815		0.4646		0.4428
		± 19	±	22	±	17	±	24	±	17	±	8	±	43	±	32
	1100	0.00472		0.00403		0.0811		2.480		0.1606		0.817		0.3836		0.3227
		± 25	±	11	±	6	±	13	±	11	±	5	±	21	±	18
	1300	0.00445		0.00400		0.0818		1.625		0.1606		0.816		0.3830		0.3217
		± 19	±	12	±	9	±	7	±	14	±	5	±	21	±	24
	1700	0.00458		0.00410		0.0831		2.229		0.1592		0.814		0.3866		0.3286
		± 21	±	32	±	16	±	28	±	31	±	11	±	73	±	35
2E	1750	0.00442		0.00397		0.0815		1.983		0.1598		0.817		0.3929		0.3382
(Total melt)		± 11	±	10	±	67	±	11	±	11	±	6	±	41	±	23

Table 5: List of samples measured by laser heating.

Sample	Weight (μg)	Remarks
1E-1	20.8	7 grains, non-metalic
1E-2	40.9	3 grains, metal
1E-3	17.0	5 crystal grains, orange color
2E-1	2.9	1grain
2E-2	3.2	1grain
2E-3	13.0	4 grains

Table 6: KMeasured amounts of noble gases in blank runs and samples, and calculated noble gas concentrations.

Sample	Weight	^{4}He	^{20}Ne	^{36}Ar	^{40}Ar	^{84}Kr	^{132}Xe	^{4}He	^{20}Ne	^{36}Ar	^{40}Ar	^{84}Kr	^{132}Xe
	μg	Measured amounts in 10^{-12} cc						Concentrations in 10^{-9} cc/g					
1E-1	20.8	23.0	1.0	1.0	313	0.0033	0.0003	792	26	9.95	4540	0.16	0.02
1E-2	40.9	38.2	0.6	0.8	224	0.0013	0.0004	775	4	1.36	144	0.03	0.01
1E-3	17.0	22.1	1.3	0.7	190	0.0002	0.0003	916	53	N.D.	N.D.	0.01	0.02
2E-1	2.9	148.0	0.6	0.7	393	0.0006	N.D.	48800	49	N.D.	60200	0.22	N.D.
2E-2	3.2	86.8	0.8	1.8	259	0.0093	0.0024	25100	109	321	12800	2.91	0.74
2E-3	13.0	329.0	1.4	2.8	444	0.0315	0.0071	24800	77	155	17400	2.43	0.55
Blank1		7.7	0.5	1.0	285	N.D.	N.D.						
Blank2		6.9	0.4	0.7	205	N.D.	N.D.						
Blank3		5.5	0.4	0.7	201	N.D.	N.D.						
Blank4		6.1	0.4	0.6	163	N.D.	N.D.						
Blank5		6.3	0.4	0.8	237	N.D.	N.D.						
Average of blank		6.5	0.4	0.8	218	<0.0005	<0.0002						

Table 7: He, Ne and Ar isotopic ratios by laser heating.

Sample	^{3}He/^{4}He	error	^{20}Ne/^{22}Ne	error	^{21}Ne/^{22}Ne	error	^{38}Ar/^{36}Ar	error	^{40}Ar/^{36}Ar	error
1E-1	0.092	0.011	0.95	0.35	0.83	0.07	0.307	0.109	454	135
1E-2	0.065	0.007	1.89	2.19	1.09	0.16	N.D.		N.D.	
1E-3	0.110	0.014	1.22	0.36	0.87	0.04	N.D.		N.D.	
2E-1	0.0017	0.0002	1.52	1.52	0.92	0.08	N.D.		N.D.	
2E-2	0.0025	0.0003	4.20	2.39	0.55	0.10	0.190	0.016	39	40
2E-3	0.0031	0.0003	3.40	0.70	0.70	0.06	0.193	0.007	112	15
Blank1	*		10.79	2.58	0.02	0.02	0.195	0.033	288	7
Blank2	*		9.45	1.94	N.D.		0.198	0.025	293	10
Blank3	*		10.16	1.28	0.03	0.03	0.193	0.019	287	14
Blank4	*		10.66	2.53	0.03	0.02	0.211	0.013	294	7
Blank5	*		N.D.		N.D.		0.184	0.016	283	10
Average of blank			10.3	0.6	0.025	0.006	0.196	0.021	289	10

* Atmospheric isotopic ratio of 1.4E-6 was assumed for blank correction.

Table 8: Kr and Xe isotopic ratios by laser heating.

Sample	$^{82}Kr/^{84}Kr$	$^{83}Kr/^{84}Kr$	$^{86}Kr/^{84}Kr$	$^{129}Xe/^{132}Xe$	$^{130}Xe/^{132}Xe$	$^{131}Xe/^{132}Xe$	$^{134}Xe/^{132}Xe$	$^{136}Xe/^{132}Xe$
1E-1	0.22	0.23	0.33	1.32	0.15	0.58	0.13	0.15
	±0.04	±0.16	±0.09	±0.85	±0.17	±0.22	±0.13	±0.19
1E-2	N.D.	N.D.	N.D.	1.05	0.35	1.24	0.61	0.35
				±0.40	±0.31	±1.00	±0.31	±0.27
1E-3	N.D.	N.D.	N.D.	2.09	0.24	1.41	0.23	0.43
				±0.93	±0.26	±1.03	±0.34	±0.33
2E-1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
2E-2	0.32	0.22	0.38	1.64	0.27	0.77	0.44	0.35
	±0.31	±0.10	±0.15	±1.06	±0.21	±0.19	±0.12	±0.11
2E-3	0.19	0.21	0.26	1.51	0.27	0.72	0.33	0.30
	±0.07	±0.06	±0.08	±0.22	±0.22	±0.13	±0.08	±0.05

same as the procedure for the total melt analysis, though the amounts of noble gases were much smaller than the other methods described above. In this experiment, five noble gas elements were separated using the Cryo-trap (Fig. 4) and each element introduced into the mass spectrometer was measured for isotopic compositions using an ion counting collector.

Measured amounts of noble gases released from the samples and blank levels are compared in Table 6. As the ^{4}He abundances from samples are much larger than the blank level, concentration of He can be determined with relatively high accuracy. Calculated concentrations for the samples are compatible with those determined by the total melting and stepwise heating experiments. Abundances of Ne and Ar from the samples, however, are comparable to the blank levels, resulting in larger uncertainties for calculated concentrations and isotopic ratios (Table 7). Though blank levels are lower than the amounts of Kr and Xe from samples, experimental errors for isotopic ratios are large because of the extremely small amounts of these gases ($\leq 10^{-14}$ cm^3 STP).

Though experimental errors are generally large, the obtained results by laser heating resemble the general trends determined by the total melting or stepwise heating experiments using relatively large sample sizes (>mg). If we measure samples with abundant noble gases of solar origin implanted into the grain surface (2-3 orders of magnitude higher than those of the 2E sample), isotopic compositions of light noble gases He, Ne and Ar would be determined with much higher accuracy and precision.

3. REMARKS FOR THE 1E AND 2E SAMPLES

Based on the noble gas data obtained in this work, 1E might be produced from some ordinary chondrites. Low concentration of Xe is compatible with petrologic type of 6. This was irradiated by cosmic-rays in space as a relatively large object for about 9 Ma. Radiogenic ^{40}Ar concentration of 1E indicates that the parent body was heavily shocked 1 Ga ago.

High concentrations of primordial noble gases suggest that 2E resemble characteristic features of carbonaceous chondrites. Radiogenic ^{4}He and ^{40}Ar concentrations (10^{-5}cm^{3}STP/g) are in the range of unshocked chondrites, indicating old gas retention age (>4 Ga). Observed excesses in ^{80}Kr and ^{82}Kr at 900°C of stepwise heating would have been produced by neutron capture reaction on ^{79}Br and ^{81}Br in the meteorite. Production of secondary neutron

in the meteoroid requires a large preatmospheric body and relatively high concentrations of volatile elements like halogens. The high concentrations of halogens are confirmed by the high $^{129}Xe/^{132}Xe$ ratio (about 2) in the 2E sample, because about half of ^{129}Xe should be an in situ decay product from extinct ^{129}I. Xe-HL is observed in 900°C fraction. Cosmic-ray exposure age is about 7 Ma. $^{129}Xe/^{132}Xe$ ratios up to 2 are commonly observed for bulk CV chondrites. Primordial Kr and Xe concentrations are in the range for CV3 chondrites. All the noble gas isotope signatures determined in this study are compatible with reported and our noble gas data on Allende CV3 chondrite. This strongly suggests that the 2E sample probably comes from the Allende meteorite.