BULK DENSITY MEASUREMENTS OF METEORITES. S. L. Wilkison[1] and M. S. Robinson[1], [1]Department of Geological Sciences, Northwestern University, Evanston, IL 60208.

Introduction: We present preliminary density measurements of meteorites from the Field Museum and Northwestern University meteorite collections. Based on the modified Archimedean method of Consolmagno and Britt [1], we measured the bulk densities of several meteorites and known standards. The purpose of our study is to provide additional meteorite density measurements to the dataset provided by the original study, and to provide a rigorous quantification of the errors in the method, both in precision and accuracy. Our results are similar to those determined by Consolmagno and Britt [1]; statistical analysis of our data shows the precision to be ~1% and the accuracy to be better than 1%.

The density of meteorites is an important property in the determination of the link between meteorites and their parent bodies. A comparison between the densities of ordinary chondrites and the density of an S-type asteroid would be a useful tool in investigating the parentage of ordinary chondrites and for understanding the internal structure of asteroids. Meteorite densities cannot be determined with a classical Archimedean method in curated collections; liquids such as water can contaminate, alter, or destroy the sample.

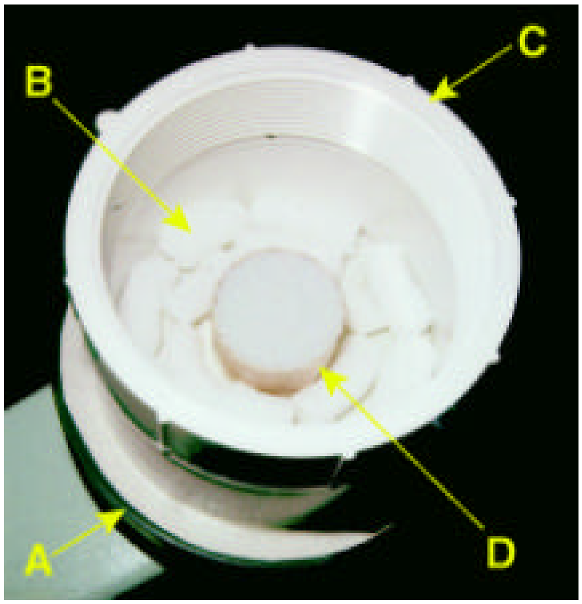

Figure 1: Experiment setup (A) Base of the vibrating platform, (B) Styrofoam pellets, (C) Plastic PVC container (D) Sample container with glass beads.

Method: Consolmagno and Britt [1,2] examined the porosity and bulk density of 40 types of meteorites from the Vatican Observatory collection of meteorites. Their density measurement technique utilized a modified (non-contaminating) Archimedean method with glass beads substituting as the liquid. This creative technique is also applicable to other types of samples that would be contaminated by the use of liquids. Porosity measurements are beyond the scope of our study, but we add new bulk density measurements to their data as well as confirm the accuracy of their study.

We used a slightly adapted version of the procedure used in the Consolmagno and Britt study [1,3]. First, the sample mass is measured on a Mettler Toledo balance. Next, the sample is immersed in a container of 250 - 425 μm size (40 - 60 wire mesh size) glass beads. The glass beads used in the experiment were manufactured as abrasive blasting media by the McMaster-Carr Company. Sample containers consist of variously sized copper cups. Containers that were flat-bottomed and massive (as compared to plastic containers) aided in the consistency of the measurements, especially when the sample mass was low. The sample is shaken in a reproducible manner on a 6 inch diameter vibrating platform (Vibrator Model No. 2), originally designed as a dental materials shaker by the Buffalo Manufacturing Company. To keep glass beads from spilling off the platform onto the counter, a plastic container was added to the platform (Fig. 1). The measurement container is then placed within this container on the platform. Styrofoam packing pellets are also arranged around the sample container to prevent the container from moving around on the platform. The sample container is rotated in a repeatable manner, every ten seconds, to allow for even shaking and compaction of the glass beads throughout the container. Shaking times ranged from 30 to 90 seconds on the low or medium settings of the vibrating platform, depending on the size of the container used. The beads are leveled with a straight edge along the top of the container. The mass of the container, beads, and sample is then measured. The procedure is also performed without the sample to gain a measure of the mass of the beads and the container only. The volume and bulk density of the meteorite is then determined [1,3].

Measurements were repeated 34 times for each sample, with the highest and lowest values thrown out of the dataset. The average, median, and standard deviation were calculated from the remaining 32 measurements and are listed for each sample in Table 1. Standards of known density were measured to test the accuracy of the method. The standards were obtained from the Applied Physics Laboratory (APL), Johns Hopkins University, and consist of small rectangular pieces of copper, steel and aluminum. Preliminary measurements of the meteorites from the Northwestern University and Field Museum collections are also listed in Table 1. The precision of the measurements was calculated by dividing the standard deviation by the average of the measurement. The accuracy was calculated by dividing the difference between the observed and predicted measurements by the "truth". The "truth" value is the known density from APL (for the copper, steel, and aluminum), or by Consolmagno and Britt [1,3] for the Allende and Pultusk meteorites.

Results: Our measurements of the standards match the densities provided by APL to better than 1% (see Table 1). The measurement of 8.81 g/cm^3 for the copper standard is 0.9% accurate to the known density (8.89 g/cm^3). The aluminum standard density measurement (2.69 g/cm^3) is also very close to the known density (2.70 g/cm^3). The steel standard measurement (7.86 g/cm^3) is not as precise as the other standards, but it is still within acceptable levels of accuracy (0.3%).

Allende and Pultusk yield bulk densities comparable to the values provided by the Consolmagno and Britt study [1,3]; our measurement of Allende is 2.89 g/cm^3, while their measurement is 2.92 g/cm^3. Our measurement of Pultusk is 3.48 g/cm^3, while their measurement is 3.41 g/cm^3. Our density measurements for the Aumieres (3.25 g/cm^3) and Forest City (3.32 g/cm^3) meteorites were not measured by the Consolmagno and Britt study [1,3].

Sources of error in the method are the relation of the size of the sample to the container, shaking and compaction, the human error involved in leveling the beads, and duplicating the environmental conditions of the study. Repeatable shaking and leveling of the beads is a necessary requirement for accurate and precise measurements. Fluctuations in humidity and temperature affect the amount of static electricity between the beads and between the beads and the container. We believe that the volume of the sample compared to the volume of the container is the largest source of error in the method. The best value is obtained when the sample volume is close to the volume of the container.

Conclusions: This study is in its preliminary stages, however, we have shown that the density technique pioneered by [1,2,3] is reliable. Density measurements of meteorites provide another tool in the continuing search for a link between meteorites and their asteroidal parent bodies. Consolmagno and Britt [1] found a density range of 2.95 g/cm^3 to 3.53 g/cm^3 for ordinary chondrites, in contrast to the bulk density of Ida, 2.7 ± 0.7 g/cm^3 [4]. Spacecraft NEAR, scheduled to go into orbit around Eros in February 2000, will determine the density of Eros from its mass and volume [5]. If Eros, an S-type asteroid, has a similar density to that of Ida and the geochemical data confirms that Eros is an ordinary chondrite [6], we can calculate the bulk porosity of the asteroid. For example, if we took the ratio of the density of Ida (another S-type asteroid) to the density of the ordinary chondrites, 2.7/3.3 = 0.8, we would obtain a value of 20% porosity for the asteroid.

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References: [1] Consolmagno G. J. and Britt D. T. (1998) *Meteoritics & Planet. Sci., 33*, 1231-1241. [2] Consolmagno G. J. and Britt D. T. et al. (1998) *Meteoritics & Planet. Sci., 33*, 1221-1229. [3] Britt D. T. and Consolmagno G. J. (1997) *LPS XXVIII*, 159-160. [4] Belton M. J. S. et al. (1995) *Nature., 374*, 785-788. [5] Robinson M. S. (1998) *Paul Pellas Symposium*, 60-61. [6] Goldstein J. O. et al. (1997) *Space Science Reviews, 82*, 169-216.

Sample	Type	Avg ρ (g/cm^3) (n = 32)	Std	Median	%Error (Precision)	"Truth"	%Error (Accuracy)
Cu	standard	8.81	0.13	8.82	1.6	8.89	0.9
Al	standard	2.69	0.04	2.68	1.6	2.70	0.4
Steel	standard	7.86	0.27	7.87	3.4	7.84	0.3
Allende	CV3	2.89	0.03	2.89	1.1	2.92 ± 0.06	1.1
Pultusk	H5	3.48	0.02	3.48	0.7	3.41 ± 0.05	2.1
Aumieres	L6	3.25	0.04	3.24	1.3	. . .	. . .
Forest City	H5	3.32	0.02	3.32	0.7	. . .	. . .

Table 1: Bulk density measurements