the Langmuir-Kingdon self-ionization technique.) Furthermore (*4, 5*), beam intensities at distances of the order of moon radii, from line sources with products of pressure, p, in millimeters of mercury and width, b, in centimeters of the order $pb \sim 10^{-3}$ and lengths of 1 cm, are approximately 4 to 1 atoms cm^{-2} sec^{-1} for Li, Na, K, and Cs. For these intensities, which are single line sources of 1 cm length, one assumes no focusing properties of the beams. For multiple sources having total lengths of the order of 10 to 100 cm, ample particle intensities could be received at distant detectors, and therefore information could be transmitted between any two stations on the surface of the moon.

There is another interesting aspect if neutrons were to be used as a particle beam (and there could well be advantages of detector sensitivity in the use of thermal neutrons). For a neutron describing a circular orbit around the moon, the time of flight between points at opposite ends of a diameter is approximately 3200 seconds. Therefore, because of the lifetime of the neutron alone, the intensity at the receiver would be reduced by approximately a factor of 20. However, considering an increase of intensity due to the focusing effect, especially in pole-to-pole transmission, thermal neutron sources of relatively low intensities might be very useful in communications.

The moon's gravitational (and magnetic-free, *6*) field could be used to increase tremendously the dispersion of a molecular-beam apparatus. A typical molecular-beam spectrometer, with an inhomogeneous magnetic field of 10^5 gauss cm^{-1} and of 50 cm in length, produces a deflection of the order of 2×10^{-4} radians in the trajectory of a 1-nuclear-magneton particle. If the axis of the beam apparatus were pointed vertically upwards at a point on the moon's surface, then the particles deflected by the inhomogeneous field would describe parabolic paths out to considerable distances from the moon's surface. The moon's gravitational field would serve as a velocity selector of a particle's horizontal velocity, and particles deflected at different angles to the vertical would fall back to the moon's surface at different distances from the beam source.

In the case of the beam apparatus just considered, if the beam particle velocity were of the order of 10^5 cm sec^{-1}, then the time taken for the particles to return to the moon's surface would be approximately 1200 seconds, and the horizontal deflection of the 1 nuclear magneton particles would be approximately 200 m (as compared with displacements of the order of tenths of millimeters in typical molecular beam spectrometers). In order to retain the necessary resolution for this experiment, typical collimated beams of the order of 3×10^{13} particles per second from a single 1-cm line source might be employed. After following the above trajectory, this beam would be reduced to an intensity at the detector of approximately 10 to 50 particles cm^{-2} sec^{-1}. For the alkali metal atoms these beams could be readily detected with present-day techniques.

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Analysis of Copper and Brass Coins of the Early Roman Empire

Abstract. *X-ray fluorescence analysis of 14 copper and brass coins of the early Roman Empire shows differences in composition between coins minted in Rome and in France. Concentrations of tin, lead, and antimony are nearly always less than in coins minted before 29 B.C. or after 54 A.D. Older coins were not melted to make copper coins of the early empire.*

Analyses of ancient coins are important to numismatists and archeologists. Questions such as the location of the mint of a group of ancient coins, or the existence of counterfeits, may be answered by quantitative analyses. Coin analyses may show differences in sources of ore for the metals and yield information regarding ancient technology. Such questions may be answered by analysis of ancient coins by x-ray fluorescence (*1*).

Most early analyses of Roman brass coins are incomplete and inaccurate; Caley's (*2*) gravimetric and spectrographic analyses are the most accurate available. Chemical analyses are destructive; although less accurate, x-ray fluorescence analysis is less destructive than most techniques and is more suitable for rapid examination of large numbers of coins.

Hall (*3*) reported a surface depletion of copper in Roman imperial silver coins; he warned that such depletion may cause inaccuracy in x-ray fluorescence analyses because only a thin surface layer (not more than 0.002 cm) of the coin is analyzed. Carter (*4*) demonstrated that light electropolishing of Roman coins in certain solutions produces surfaces having essentially the same compositions as the interiors; accurate analysis by x-ray fluorescence is thus permitted. An improved method of cleaning coins before analysis by x-ray fluorescence is air blasting with a fine abrasive powder such as aluminum oxide (*5*); surface corrosion products and up to 0.002 cm of metal should be removed; despite change in appearance of the surface, the coin remains essentially intact.

Fourteen copper coins of the early Roman Empire, from 21 B.C. to about 54 A.D., were analyzed for 25 elements by x-ray fluorescence. The coins conveniently divide into two groups: 12 of almost-pure copper and two of brass (copper-zinc). Both brass

Table 1. Principal components of 14 Roman copper and brass coins minted between 21 B.C. and 54 A.D. Abbreviations: c, *circa*; N, none detectable.

Coin		Concentration (wt. %)					
No.	Date	Fe	Cu	Zn	Sn	Sb	Pb
				B.C.			
R-78	21	0.44	80.7	18.1	0.03	0.07	0.14
R-94	c 10– 6	.15	98.0	N	.17	.79	.12
R-80	c 5	.07	99.3	N	.01	.03	.05
				A.D.			
R-81	12–14	.38	87.0	12.0	.13	N	.06
R-60	22–23	.13	99.3	N	.01	N	N
R-96	c 22–28	.10	99.4	N	.01	N	N
R-97	34–35	.28	99.2	N	.01	.03	.06
R-63	c 34–37	.16	99.4	N	.01	.06	.08
R-79	c 34–37	.25	99.3	N	.01	.04	.06
R-95	c 34–37	.04	99.6	N	.01	.04	.07
R-98	37–38	.06	99.6	N	.01	N	.03
R-17	41	.11	99.4	N	.01	N	N
R-71	42	.08	99.4	N	.01	N	.02
R-82	42–54	.09	99.5	N	.01	N	.02

coins, R-78 and R-81, are of much lower density than the other coins. One copper coin was of low density, apparently because of internal porosity. All were minted in Rome except R-94 and R-81, which were made in Lugdunum (Lyons, France).

The more important components are listed in Table 1; elements undetected include titanium, vanadium, chromium, palladium, tellurium, platinum, gold, bismuth, and arsenic. The following elements occur randomly in low concentrations in the coins: silicon (0 to 0.2 percent), phosphorus (0.05 to 0.1 percent), sulfur (0.01 to 0.1 percent), chlorine (0.04 to 0.1 percent), calcium (0.01 to 0.08 percent), and selenium (0.01 to 0.03 percent). The constituents of greatest interest are manganese, iron, cobalt, nickel, copper, zinc, silver, tin, antimony, and lead.

Manganese occurs in the brass coins (0.02 percent in R-78 and 0.01 percent in R-81) but not generally in the copper coins; the one exception is R-97, which contains less than 0.005 percent. Percentages of iron in the brass coins are significantly higher than in the copper; either iron contaminated the zinc ore or the brass assimilated iron from iron melting pots (iron is more soluble in molten brass than in copper).

Only three coins contain detectable cobalt: R-82 has only a trace ($<$ 0.005 percent), while R-96 and R-60 contain 0.02 percent. These two coins, which were minted at about the same time (Table 1), also have unusually high nickel contents; the source of ore for these two probably differed from that for the rest of the coins minted in Rome.

The nickel content of most coins is less than 0.02 percent; four contain appreciable concentrations: R-94, 0.15 percent; R-81, 0.10 percent; R-96, 0.27 percent; and R-60, 0.31 percent. The first two of these four coins, having about the same nickel concentration, were minted in Lugdunum; the copper ore that was used there apparently contained appreciable nickel.

Caley (*2*) reported 22 percent zinc in two coins of Augustus, whereas R-78 contains 18.1 percent; however, the zinc content of coins of a given emperor often varies over a range of a few percent (*2*). The almost-pure copper coins contain no detectable zinc; this means that there was no mixing of brass with copper during this period. The silver contents of most of the coins vary from 0 to 0.08 percent. Two exceptions, both minted before Christ, are R-78 (0.20 percent) and R-94 (a Lugdunum coin, 0.27 percent).

The concentrations of tin are highly significant; they are much lower in copper coins of this period than in coins minted either during the Republic (before 29 B.C.) or after 54 A.D. This fact indicates that coins minted during this period were made directly from the ore; tin contents would have been greater had the coins been minted from melted coins or other objects. The two coins having appreciable concentrations of tin, R-94 (0.17 percent) and R-81 (0.13 percent), were both minted in Lugdunum; this is another marked difference in composition between coins made in Lugdunum and in Rome, probably indicating a different ore source.

Seven coins contain no antimony. This is significant because copper coins made before 29 B.C. or after 54 A.D. contain appreciable antimony. Only coins made between 12 and 54 A.D. have no detectable antimony. Coin R-94, made in Lugdunum, contains 0.79 percent antimony, an unusually great amount.

Lead concentrations vary from 0 to 0.14 percent, although all coins minted between 5 B.C. and 54 A.D. contain less than 0.08 percent; such low concentrations occur only in Roman copper coins of this period. Every coin containing no detectable lead also contains no antimony and only 0.01 percent tin; in the three other coins containing 0.01 percent tin and no antimony, there is only 0.02 to 0.03 percent lead.

The analyses are accurate enough to permit the following conclusions:

1) Copper coins of the early Roman Empire are remarkably uniform in composition, most of them containing less tin, antimony, and lead than coins of other periods.

2) Coins minted in Lugdunum contain more tin and nickel than coins minted in Rome; the two mints probably used coppers from different sources.

3) Coins R-60 and R-96, containing much more nickel and cobalt than the others minted in Rome, may have been made from metal from a different source.

4) Roman copper and alloyed-copper coins of earlier periods contain much more tin, antimony, and lead; thus it is certain that the metal for copper coins minted in the early imperial period was not obtained by melting earlier coins.

5) Counterfeits of early imperial copper and brass coins would in all probability have a different composition from the genuine; thus they could be easily detected by x-ray fluorescence analysis.

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References and Notes

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