CHARACTERISTIC $\gamma$- AND X-RADIATION IN THE PLANETARY SYSTEM

PAUL GORENSTEIN and HERBERT GURSKY
American Science and Engineering, Cambridge, Mass., U.S.A.

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1. Introduction

Natural phenomena are the source of fluxes of X-ray and $\gamma$-radiation that are readily observable in the vicinity of individual planets. These regimes of the electromagnetic spectrum are unique because characteristic atomic and nuclear lines are important components of the total emission and unambiguously indicate the presence of certain elements. These lines can serve as a basis for determining the absolute abundances of many of the elements that predominate in the outermost layer of the planet. Hayakawa (1962), has discussed certain aspects of the production of the hard electromagnetic
emission in an earlier paper. In this review we address ourselves to the question of what can be expected in the way of determining chemical abundances from a vehicle in orbit around a planet that carries presently existing instrumentation for the detection of characteristic X- and γ-rays. Remote sensing and passive observation is the framework of the measurements we consider. Mechanisms for producing these characteristic lines are discussed and we describe various estimates for the flux plus some experimental results that have appeared in the literature. All of the finite experimental results that have been reported so far apply to the earth's atmosphere and the moon; in addition, there are measurements that represent upper limits for some of the other planets.

Remote observations obtained from orbit cannot be expected to compete in sensitivity or precision with measurements performed at specific landing sites where sample preparation is possible and active means such as z backscattering (Turkevich et al., 1967), neutron bombardment, or electron microprobe analysis can be employed to interrogate the surface. However, the remote observations are complementary to the in situ measurements in the sense that they have the capability of determining the average chemical composition of a large region and, in the absence of an atmospheric cover, have the potential for exploring the entire planetary surface and possibly discovering new areas with distinct chemical compositions. Since it does offer this important capability, it is likely that remote geochemical sensing will play a prominent role in future programs of planetary investigation.

Strong emphasis is placed upon the identification of lines and the 'geochemical' aspects of the X-ray and γ-measurements although there are also important implications concerning various geophysical phenomena. We concern ourselves only with how measurements of the hard electromagnetic radiation can be used to obtain elemental abundances and not with the mechanism itself responsible for producing the radiation except as needed for estimating or interpreting the spectral composition of the emitted flux. The potential importance of observations of this kind depends on whether or not the planet is covered by a gaseous atmosphere. If a gas cover is present, then one can only detect those elements which are its important constituents, presumably H, C, O, and N (but not He). When the atmospheric cover is absent, then it is possible to carry out widespread exploration and make use of spatial resolution to search for inhomogeneities on the planetary surface. Additional elements which may be seen are: Na, Mg, Al, Si, K, Ca, Fe, Th, and U. Planets which belong to this category are the moon, Mercury, and some satellites of the large planets. Mars belongs to a special category because its atmosphere is opaque to X-rays but not to γ's.

γ-ray observations are most sensitive to the presence of K, Th, U from natural-occurring sources plus H, C, O, Si, Al, and Fe through cosmic-ray effects. X-ray measurements are sensitive to Mg, Al, Si, K, Ca, and Fe. Favorable conditions and large concentration allow the detection of other elements. The quantity of material which is sampled is one mean free path of absorption of the outgoing radiation. Typically, this is about 25 grams/cm$^2$ for the γ-rays and about $10^{-3}$ grams/cm$^2$ for the X-rays. Spectral components of greater energy come from a correspondingly