

## IRRADIATION-INDUCED PARAMAGNETIC SPECIES IN LUNAR PLAGIOCLASES.\*

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In addition to electron paramagnetic resonance (EPR) spectra due to  $\text{Fe}^{3+}$ ,  $\text{Ti}^{3+}$ , and  $\text{Mn}^{2+}$  observed in lunar plagioclases, EPR spectra, observed in some lunar samples (1,2), may be due to paramagnetic states of defects in the crystal structure of one of the lunar minerals. Irradiation of a sample from crystalline rock 12021 enhanced the intensity of some of these paramagnetic states (3). We will show below that some of these states are due to defects in the crystal structure of the plagioclase fraction of lunar samples, and that the paramagnetic states of the defects are present in the as-received samples in low concentration ( $10^{14}$  to  $10^{15} \text{ gm}^{-1}$ ), but that the atomic configuration upon which the paramagnetic electron state is localized has a concentration sufficiently high to be a significant factor in the chemical anomalies that Wenk and Wilde describe (4).

Measurements of the EPR spectra at 9 GHz as a function of irradiation ( $^{137}\text{Cs}$  gamma rays) and annealing (100 to 550K) have been made on plagioclase (plg) fractions (> 99% plg) from 14053-47 and 14321-166 (5) and on plg-rich (> 80% plg) samples 67075-21, 67455-16, 60051-14, 60015-68, 62242-2, and 68416-13. The spectra observed in a sample of 60015-68 as received and after a  $5 \times 10^5 \text{ R}$  irradiation at  $\sim 330\text{K}$  are shown in Fig. 1. A new component (labeled "O" centers) and an increase in the intensity of the  $\text{Ti}^{3+}$  component are observed after irradiation. No other changes in the spectrum were found between 0 and 10 kG. The spectrum of the plg fraction of 14321-166 is shown in Fig. 2 after a  $10^6 \text{ R}$  irradiation. Prior to irradiation, the spectrum of 14321-166 was similar to that of 60015-68, with the exception of the F component, identified in Fig. 2a, due to a contaminating ferromagnetic mineral phase. The irradiation-produced "O" components, not present initially, are present after the irradiation. A similar effect was observed in the plg fraction of 14053-47. After irradiation there was little change in the intensity of the  $\text{Ti}^{3+}$  component in the spectra of either sample. The structure of some of the "O" components and the effect of increasing the radiation dose at  $\sim 330\text{K}$  are shown in Fig. 2b, c, d, and e. On the basis of the data for the plg fraction of 14053-47 and 14321-166, the "O" components are assigned to the spectrum of the plg fraction. The complexities of the "O" spectral components are illustrated in Fig. 3. At least three distinct types, whose relative intensities are sample and temperature dependent, are resolved. The low-temperature irradiation also produced a new component in two of the samples whose spectra are shown in Fig. 3, the "E" component. This component has a shape and a g-value equivalent to those of a radiation-produced component in lunar pyroxenes (2). This component is resolved on the basis of its intensity as a function of spectrometer power as compared to that of the "O" components (Fig. 3, a and b).

Irradiation at 78K and measurement without warming the sample above the spectrometer temperature ( $\sim 100\text{K}$ ) produces a ten-fold increase in the

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intensity of the "O" components. Hyperfine structure in the spectra of the "O" components is not observed. The "E" component disappears when the sample is warmed for 5 minutes at a temperature  $> 160\text{K}$ . The "O" components disappear when samples are warmed to temperatures  $> 500\text{K}$  for 5 minutes. Reirradiation at  $78\text{K}$  produces the same effect as the initial irradiation at  $78\text{K}$ . The concentration of the defects at which the paramagnetic states are localized ranges from  $10^{18}$  to  $10^{19}\text{ gm}^{-1}$  in all of the samples. These defects thus comprise of the order of 0.1 atomic percent.

On the bases of these data, we conclude that: (i) the "O" centers have a diamagnetic precursor state which may be either an "electron" or "hole" trapping site; (ii) at temperatures  $< 550\text{K}$  the "O" centers are stable, but the paramagnetic states of the "O" centers will anneal; (iii) the "O" centers are structural defects of the plg fraction, (iv) the absence of resolved hyperfine structure indicates that the atoms on which the paramagnetic states are localized have a low ( $< 5\%$ ) natural abundance of isotopes with nuclear magnetic moments, and hyperfine interactions with nearest-neighbor nuclei are either weak or are not present; (v) the concentration of "O" centers is high enough to be a significant factor in the chemical anomalies of lunar plg (4). It is difficult on the basis of these data to identify the atomic configuration on which the paramagnetic state is localized. We note that the g-values of the "O" components are similar to those which have been observed for the spectral components of  $\text{O}^-$ ,  $\text{O}_2^-$ , and  $\text{O}_3^-$  produced by irradiation of diamagnetic oxides (5,6).

## References

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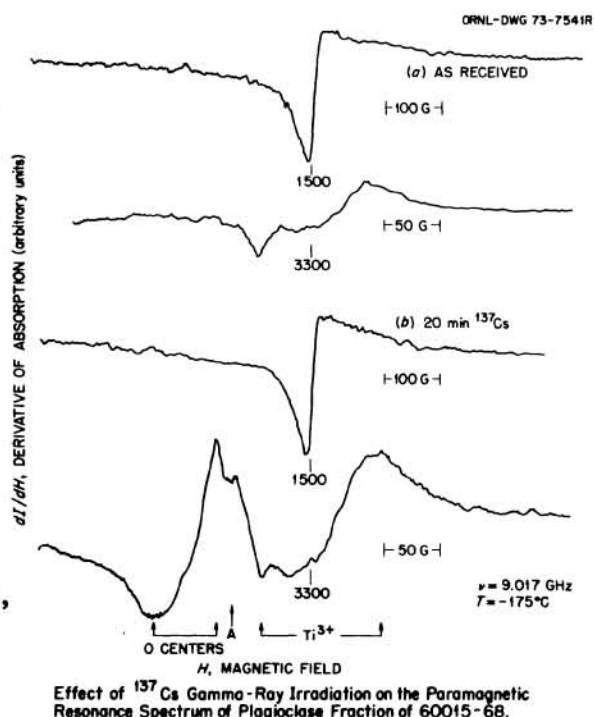


Figure 1

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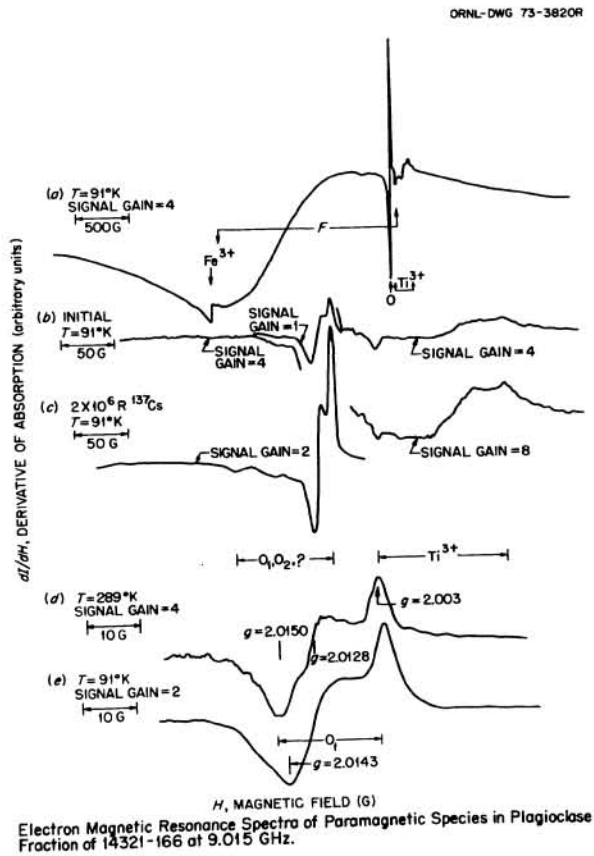


Figure 2

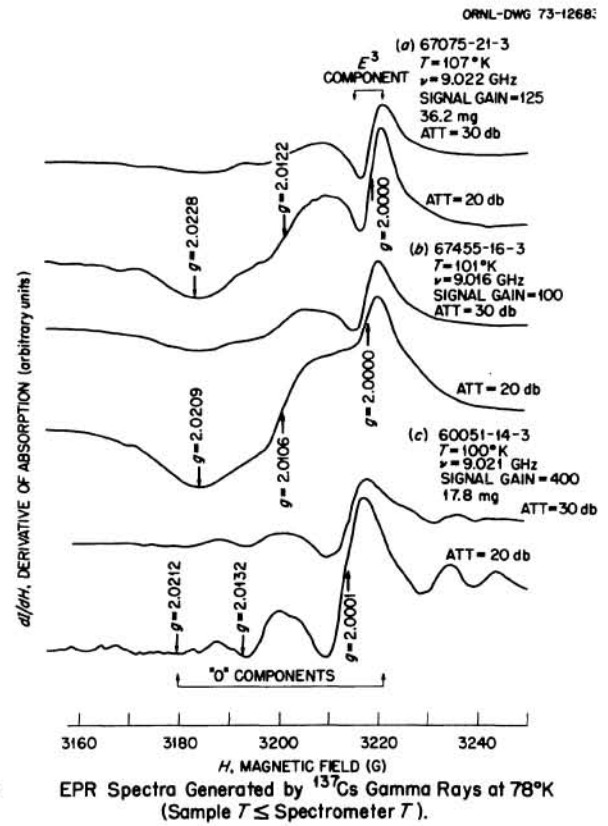


Figure 3