A NEW TYPE OF MAGNETIC MEMORY PHENOMENON IN ROCKS

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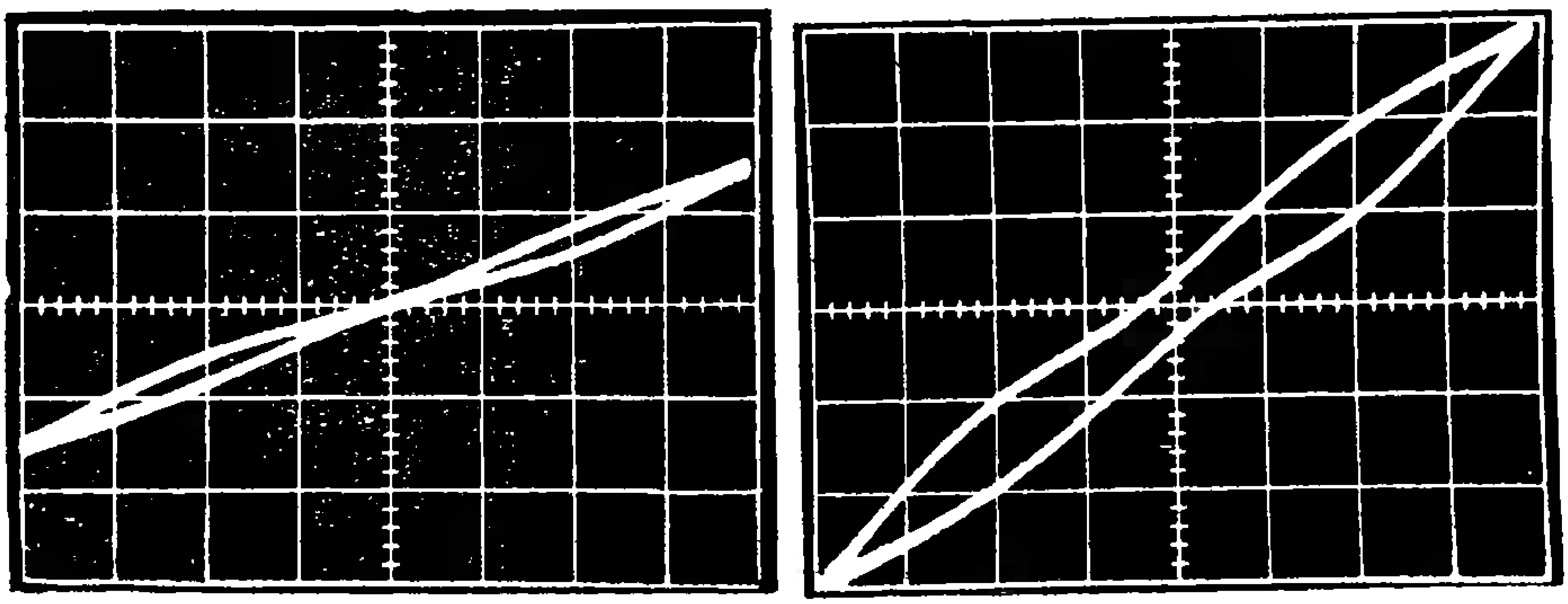
Introduction

In a recent paper Likhite and Radhakrishnamurty[1] have reported the different types of low field hysteresis loops, generally known as Rayleigh loops, obtained for basaltic specimens, the most interesting one observed among them being the constricted loop. It is now well known that several magnetic alloys[2-4] and also some rocks[5-6] show major loops with constrictions which can be attributed to either the magnetic anisotropy or the presence of more than one magnetic phases in them possessing widely different magnetic properties. The constricted major loop shown by an alloy or a rock is more or less a permanent feature of the material concerned until and unless the same is changed irreversibly by heat treatment. But in the case of rocks giving constricted Rayleigh loops, we have observed that the constriction disappears when they are subjected to fields of over 50 Oe A.C. or D.C. or when their temperature is raised or lowered with respect to the room temperature (24° C.) by a few tens of degrees. However, in all these cases the rocks regain their original condition after sometime and show exactly the same constricted loop as they did before they were subjected to the higher field or temperature changes. This recovery, displaying an extraordinary 'memory', is somewhat akin to the one reported by Blackman *et al.*[7] from studies on magnetic minerals at various temperatures using a different technique. Also this phenomenon bears a great similarity to the one observed by Brissonneau[8] during studies on magnetic diffusion after-effect in a very dilute solid solution of carbon in iron, at a temperature of $-21 \cdot 3°$ C. Nevertheless it may be clearly mentioned at the outset, that the phenomenon described herein is at room temperature and has a direct bearing on palæomagnetic measurements, which is being reported elsewhere by Radhakrishnamurty *et al.*[9]



a *b*

FIG. 1. Types of constricted Rayleigh loops obtained in rocks. *a*, Totally constricted loop; *b*, Partially constricted loop.

In Figs. 1 *a* and 1 *b* are shown the two types of low field constricted loops observed in rocks. The loop in Fig. 1 *a* which is almost collapsed to a line in the centre may be termed "totally constricted loop" whereas that in Fig. 1 *b* may be called a "partially constricted loop". These constricted loops shown by the rocks are not due to an overall magnetic anisotropy, because all the loops remain the same for different orientations of the samples with respect to the direction of the magnetizing field. In these figures, as well as in those of 2, 3 and 4, one small division on the horizontal axis represents 0·5 Oe, and that on the vertical axis corresponds to 17×10^{-3} emu of magnetic moment.

The constricted loops have been observed for virgin specimens of fine and coarse-grained basalts from lava flows and of dolerites from dykes. The Curie temperature of these rocks range from 200 to 500° C. and the magnetic mineral constituents are different titanomagnetites. In a few cases, the rocks showed constricted loops after they were heated to about 500° C. and cooled even though in their virgin state they yielded simple loops. This clearly indicates that at least in the case of some rocks the heat treatment alters their state so that they begin to show constricted loops.

Time of Recovery

The constriction in the Rayleigh loops shown by different rocks in fields of ± 10 Oe, diminished gradually when the field was increased and disappeared in fields of about ± 50 Oe. After this the loops did not show constriction when the field was decreased back to 10 Oe. However, all the rocks regained their original state and showed constricted loops after sometime.

In Figs. 2 *a* and 2 *b* are shown the constricted and ordinary loops obtained for one of the specimens before and after subjecting it to a high field respectively. The main differences in the two loops are, firstly, the hysteresis loss is more after removing the constriction as shown by the larger area of the loop in Fig. 2 *b*, and secondly, the maximum intensity of the specimen is also greater in the latter case. In Figs. 2 c to 2 *f* are shown the loops observed for the same specimen after a lapse of 1, 7, 13 and 30 days respectively. It can be seen from these figures that the recovery of the initial state is some kind of an exponential process and that during the recovery there is a gradual increase in the amount of constriction accompanied by a fall in the maximum intensity

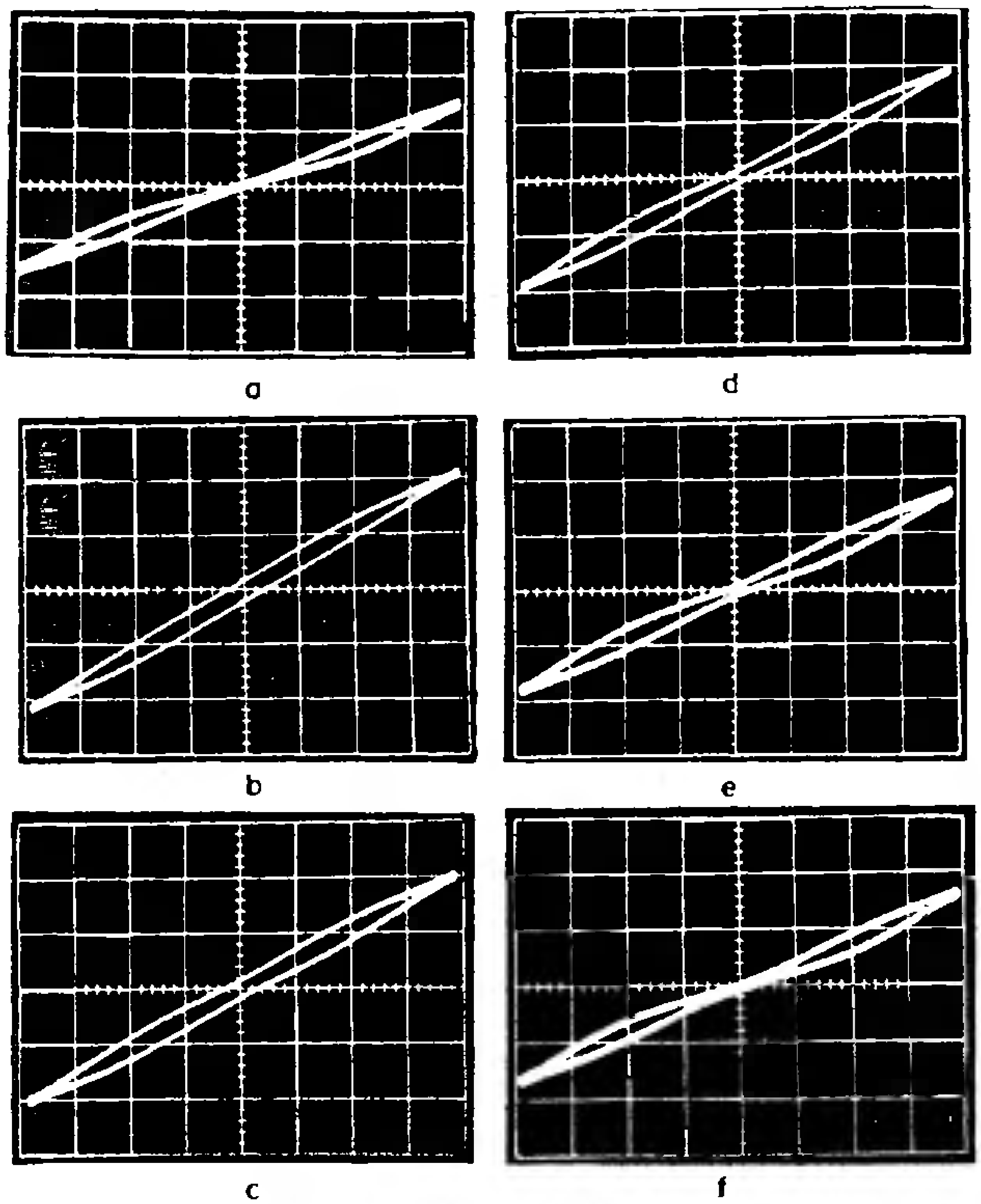


FIG. 2. Stages in the recovery of a constricted loop. *a*, Initial; *b*, After subjecting to 50 Oe; *c*, After 1 day; *d*, After 7 days; *e*, After 13 days; and *f*, After 30 days.

of the specimen until the initial state is fully regained.

The same phenomenon has been observed in the case of several rocks with recovery times ranging from a few days to about 4 weeks. Only for one rock specimen the recovery time was found to be 10 minutes, and in this case a definite tendency for recovery could be noticed just after one minute. This shows that even though the phenomenon is the same, different rocks require different times for recovery, the range observed so far being from a few minutes to a few weeks.

Further studies made on the specimen showing a 10-minute recovery time yielded following results:

1. The constriction in the loop of a specimen can be removed by subjecting it to fields of over 50 Oe A.C. or D.C. but the time of recovery is the same irrespective of the strength of the field used. This has been verified in D.C. fields of 50 to 10,000 Oe.
2. When after removing the constriction the specimen was kept in 10 Oe A.C. for observing the recovery, the loop did not show any tendency for recovery for a considerably long period. Normally the specimen showed a tendency for recovery in one minute when stored in earth's field (0·5 Oe), but in 10 Oe A.C. this tendency was not revealed even for 15 minutes which was more than the full recovery time, indicating that the recovery time of the specimen can be considerably enhanced by impressing an A.C. field on it.

Temperature Dependence

There is no provision in the apparatus at present for observing the hysteresis loop at different temperatures. However, the specimen can be heated or cooled to the desired temperature outside and quickly transferred to the specimen holder for studying its Rayleigh loop. In Figs. 3 *a*, 3 *b* and 3 *c* are shown the loops for a specimen at 0° C., room temperature (24° C.) and 100° C. respectively. It was found that the constriction in the loop disappeared when the temperature of the specimen was raised or lowered by about 20° C. with respect to the room temperature, but reappeared when the specimen was brought back to the room temperature. However, if the specimen was heated to a higher temperature (> 100° C.) then the specimen took its full recovery time to regain its initial state giving a constricted loop. It was observed that specimens with

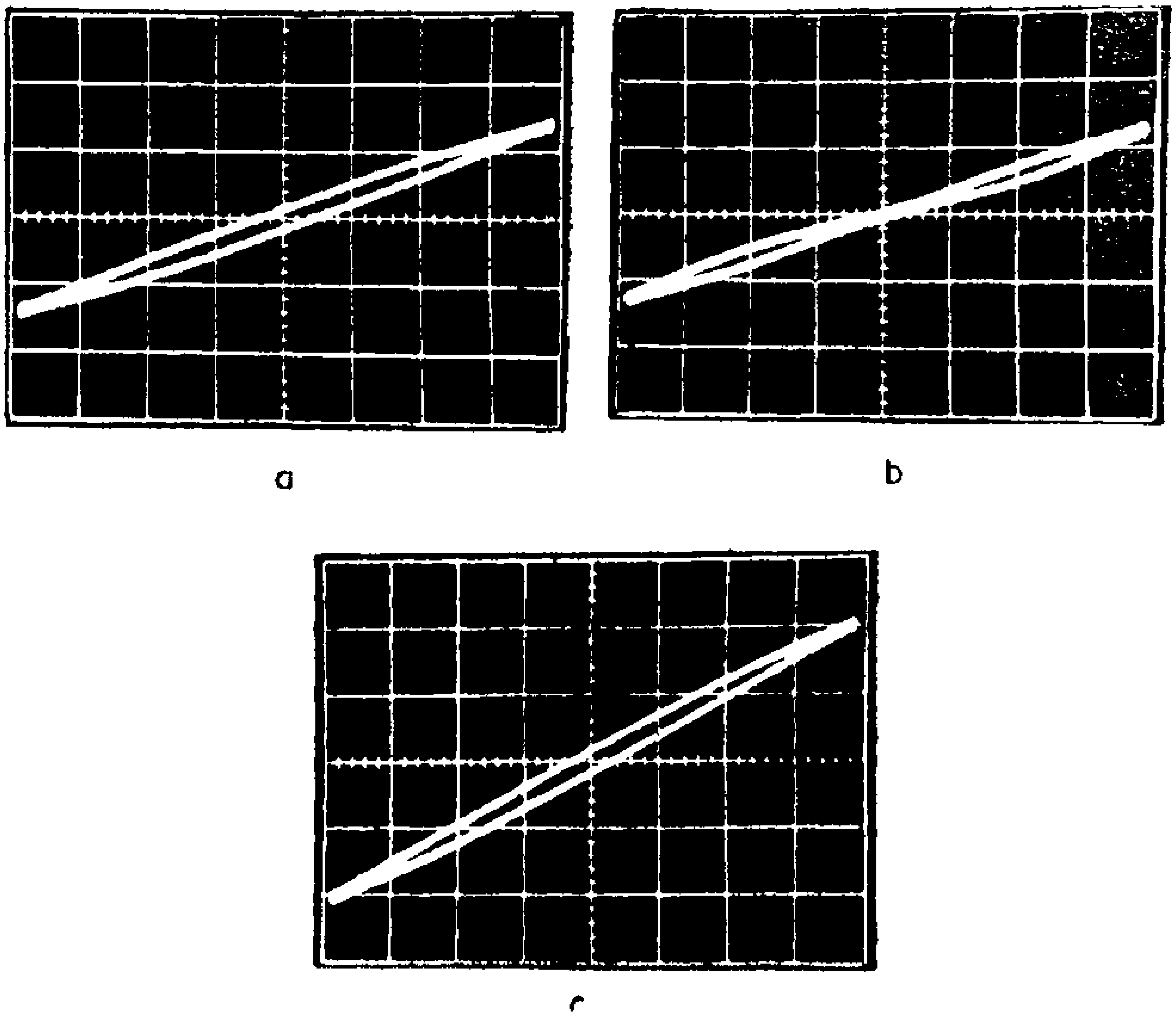


FIG. 3. Temperature dependence of the constricted loop of a rock. *a*, At 0° C.; *b*, At 24° C. and *c*, At 100° C.

different recovery periods behave in a similar way.

Dependence on Mechanical Shocks

It is rather interesting to note the delicate nature of the magnetic state of the rocks. The constriction in the Rayleigh loops of the rocks disappeared when they were subjected to mechanical shocks such as due to slight hammering. However, in these cases also the rocks regained their initial state giving constricted loops after their full recovery periods.

Line and Loop Phenomenon

The magnetic behaviour of rocks in a field of about 10 Oe A.C. varies widely. For some straight lines initially, showed thick loops on subjecting them to high fields or slight heating or cooling. In such cases also, the rocks regained their initial state and gave tilted straight lines afer a lapse of time exhibiting a memory effect.

In Figs. 4 *a* and 4 *b* is shown the behaviour of a specimen before and after subjecting it to a field of 50 Oe. The intermediate stages of the recovery obtained after lapse of 1 and 3 days are shown in Figs. 4 *c* and 4 *d* respectively. After a lapse of one week the specimen showed a tilted line exactly like the one shown in Fig. 4 *a*. It was found that the recovery in the line-loop-line memory phenomenon often occurred through the intermediate stages consisting of constricted loops and/or irregular and

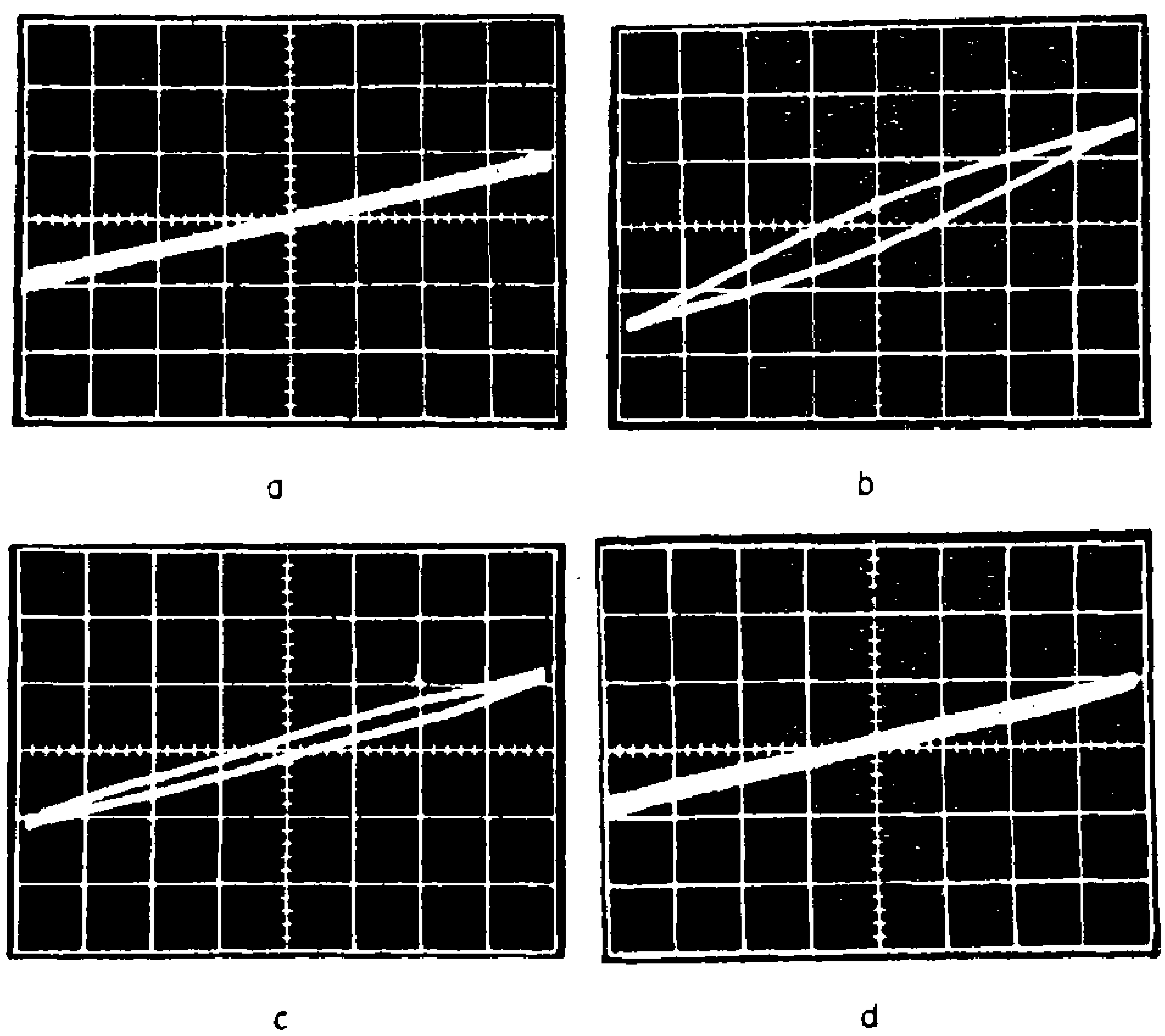


FIG. 4. Stages in the line-loop-line transition in the Rayleigh loop of a rock. *a*, Initial; *b*, After subjecting to 50 Oe; *c*, After 1 day; and *d*, After 3 days.

rocks the susceptibility is almost constant whereas for others it varies over the range of the field. The former types give tilted straight lines whilst the latter ones show thin, thick or constricted loops in low fields. As mentioned in the previous sections, the rocks showing constricted loops display a memory effect. Many rocks that show thin or thick loops, or tilted straight lines, do not exhibit any change in their behaviour after subjecting them to high ($>$ 50 Oe) fields or slight heating or cooling. However, some of the rocks which gave tilted asymmetric loops. In such cases also the time of recovery was found to vary from a few minutes to a few weeks. In general the processes and the recovery periods are similar in the two types of memory effects described in the foregoing, except for the difference in the shapes of the initial loops. Also, the recovery in the line-loop-line transition is often *via* a constricted loop so that the stability of the initial constricted loop observed in some rocks itself becomes an interesting feature.

Summary of Results

Two types of magnetic memory phenomena in low fields have been observed in rocks. The first one consists of a transition from a constricted loop to a thick loop on subjecting the rock to a high field and back to a constricted loop after a certain recovery time. This may be called the 'Constriction memory effect'. The second type involves line to elliptic loop and back to line transition with a fixed recovery period and this may be called the 'Line memory effect'. For both these transitions the physical processes occurring in the rocks are probably the same and similar to those discussed by Brissonneau[8] to account for the behaviour of the dilute solid solution of carbon in iron. He explains the variation of magnetization of iron with time due to reorientation of displaced Bloch walls from their initial equilibrium positions, through a process of diffusion. Considering the similarity of both the phenomena Neel[10] suggests that the same process of displacement and diffusion of Bloch walls may be the cause for the memory effects observed in rocks. However, it seems that these phenomena could also be caused by interacting single domain grains of varying sizes. A wide range of grain sizes is possible in volcanic rocks either due to rapid cooling or by slight alteration which may break down some of the original multidomain grains into smaller single domain grains, whose relaxation time is highly dependent on the size.[11] Thus, the presence of single domain grains of different relaxation times, in principle, can cause a variation of the magnetization of a rock containing them.

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INDIRECT POLAROGRAPHIC DETERMINATION OF STABILITY CONSTANTS

III. CDTA Complexes

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The usefulness of the indirect polarographic method for the determination of stability constants of metal ion complexes even when they are not reducible or irreversibly reduced at the dropping mercury electrode is being investigated.[1,2] This paper reports the determination of stability constants of 1-2 diamino cyclohexane tetra acetic acid (CDTA) complexes of sodium and lithium using thallium as indicator ion.

Experimental

Current-potential curves were taken on a manual polarograph. All experiments were carried out in 0·1 M potassium nitrate at 30 ± 0·5° C. A Cambridge Bench Type pH meter was used for pH measurements.

A standard solution of CDTA (M/s. Suhrid Geigy Ltd.) was prepared by the method of Pribil *et al.*[3] B. D. H. AnalaR samples of thallous sulphate, lithium nitrate and sodium nitrate were used for the preparation of standard solutions.

Results and Discussion

A one-electron reversible wave with the half-wave potential at − 0·4562 V *vs.* S.C.E., was