

CHAPTER 1.

HISTORICAL BACKGROUND OF THE DYNAMO THEORY

Various hypotheses have been proposed to explain the origin of the upper atmospheric current-systems which produce the geomagnetic variations. One of the oldest is the dynamo theory, proposed by Balfour Stewart (1) in 1882, and it is now the most widely accepted. The dynamo theory as conceived by Balfour Stewart is that geomagnetic variations are caused by the horizontal motion of electrically conducting air in the upper atmosphere across the lines of force of the geomagnetic field.

This theory was developed by Schuster (2) into a quantitative form. He showed that the S_q -variation is of the type that would arise if convective air motions exist in the conducting layer, and on this assumption he estimated the conductivity of this layer. Meanwhile, Kennelly (3) and Heaviside (4) inferred from the ability of radio waves to travel round the earth that there is an electrically conducting region, the ionosphere, in the upper atmosphere. Later radio explorations developed by many investigators clarified the complicated electrical state of the ionosphere.

Chapman (5) completed Schuster's mathematical theory of an atmospheric dynamo (6) by using a more general expression for the conductivity distribution and obtained a better agreement with observed data. He also discussed the dynamo theory of the L -field and showed that this is the only adequate theory which can readily account for the various phenomena of the lunar daily variation. Thus the dynamo theory for quiet day variations was gradually accepted, though there was some discrepancy between the estimated electrical conductivity and that deduced from radio observations.

Since recent studies on ionospheric movements (7) have revealed a much higher velocity of wind motion in the upper atmosphere than was hitherto expected, the above discrepancy can be removed. The estimated value of the total conductivity of the ionosphere (8) seems to agree with that required from geomagnetic variations. Recent rocket explorations of the ionosphere even makes it possible to deduce the conductivity from direct observations and also to identify the height of the region in which the electric currents deduced from geomagnetic variations are flowing (9).

Furthermore, there have been many successful applications of the dynamo theory for some special geomagnetic variations. The magnetic variations at the time of a solar flare or solar eclipse can be interpreted by the dynamo theory on the assumption of an increase or decrease in the electrical conductivity of the ionosphere (10)–(12), and the longitudinal inequality of the S_q -field can be explained by taking into account the obliquity of the earth's magnetic axis (13). Thus, at present, there seems to be no doubt that the regular geomagnetic variations are due to a dynamo action in the atmosphere.

In the last few years the dynamo theory of the S_q -field has been re-examined

by several investigators. Since our knowledge of the conductivity of the ionosphere has greatly increased (14), (15), it is now possible to evaluate the pattern of the wind system as well as its order of magnitude. Chakrabarty and Pratap (16) have shown that a semidiurnal wind-system can set up a current-system which accounts fairly satisfactorily the S_q -field. Maeda (17), on the other hand, has shown that the required wind-system is predominantly diurnal with a velocity of the order of 50 m/s. Maeda's analysis has been extended by Kato (18) taking into account the effect of the earth's rotation. Hirono and Kitamura (19) have also deduced the wind system, and found that the toroidal wind becomes predominant at high latitudes where the Coriolis force may cause this motion.

Since the dynamo theory has been quite successful in interpreting quiet day variations, it is reasonable to consider that the disturbance field may also be in part due to such a dynamo action in the upper atmosphere. As early as 1919, Chapman (20), (21) considered compressions and expansions of the atmosphere as a possible cause of magnetic storms, and in 1927 he noted that an atmospheric circulation could produce the disturbance diurnal variation if the conductivity in the polar region were enhanced. The first attempt at a theoretical calculations of the S_D current system was made by Rikitaka (22), who assumed a highly conducting region around the auroral zone. This study was later extended by Fukushima (23)–(25) for polar magnetic storms. He showed that polar magnetic storms are composed of a number of elementary disturbances of simple form, each of which could be interpreted on the assumption of an enhanced dynamo action due to the appearance of small, highly ionized areas in the upper atmosphere over the auroral zone.

The possible modes of wind systems related to geomagnetic variations have been discussed by Wulf (26) who suggested that all geomagnetic variations, with the exception of secular changes, are due to atmospheric winds. Vestine (27) has also deduced tentative wind-systems which could produce magnetic storms, so that experimental measurements of ionospheric winds may be used to confirm or disprove the dynamo theory of disturbances. Although wind systems cannot be inferred uniquely from magnetic changes and observations of ionospheric movements are still insufficient to obtain a world-wide picture of such wind systems, some agreement has been found with the diurnal features of atmospheric motions as deduced from radio-star scintillations and auroral motions.

Renewed interest in the dynamo theory of magnetic disturbances has arisen from the discovery of a conspicuous D_s current system at the time of sudden commencement (s.c.). As has already been described, strong evidence of a diurnal behaviour of s.c.'s, the D_s^c current-system, is found in polar regions. Since this current system seems to be of atmospheric origin, it might be produced by an enhanced dynamo action caused by a sudden increase of conductivity of the ionosphere at the time of s.c. . Since the s.c. is very abrupt change (within a few minutes), it seems reasonable to assume that the wind system in the ionosphere does not change during this time, and the change from the S_q field to the D_s^c field may be only due to a change in the conductivity in the polar regions. Assuming a reasonable conductivity change at the s.c., it is possible

to determine a consistent wind system which can produce the current systems for both the S_q and D_e^c field, provided that two current systems originate from a dynamo action in the same region.

The mathematical derivation of the dynamo theory for magnetic disturbances is first briefly described. Electric current systems for the S_q field and for magnetic disturbances are calculated assuming a reasonable conductivity distribution for each geomagnetic condition. Agreement with data obtained from actual geomagnetic variations is fairly satisfactory, and a consistent wind-system, which could produce the observed geomagnetic variations both for quiet-days and disturbances, is found by combining a diurnal with a semidiurnal wind.