A different formula for the coefficient of viscosity has been given by Fürth¹⁶. It is based on his theory of 'holes'; the liquid is regarded as a continuum of small bubbles, the size and apparent mass of which depend on the surface tension. These bubbles perform a kind of Brownian movement, and transfer energy and momentum; the coefficient of viscosity can thereby be expressed in terms of the surface tension. Fürth's formula contains an exponential factor of the same type as ours; the remaining factor cannot be compared with ours because of the entirely different assumptions made. But Fürth has shown that his formula is practically identical with Andrade's because of some empirical relations between the constants involved; and similar considerations can be applied by comparing Fürth's formula, or that of Ewell and Eyring¹⁷, with our own.

Our theory also provides an account of the variation of the apparent viscosity of liquids under the action of external forces, such as electric and magnetic fields. One general conclusion here is that the field cannot by itself produce any change in the apparent viscosity if it can be derived from a scalar potential; this appears to be in accord with the recently published experimental work of Andrade and Dodd¹⁸. On the subject of conducting liquids and the effect of alternating fields, which they have also studied, we have not yet reached any definite conclusion; this remains a subject for further study.

We hope to generalize the theory also in the following different directions. The first and most obvious step is the introduction of internal degrees of freedom of the molecules; this is probably closely connected with giving up the assumption of central forces. Then mixtures of two or more kinds of molecules have to be considered in order to obtain the laws of ordinary and thermal diffusion; the latter (Soret effect) will be of special interest, as no theory for liquids seems to exist (see the dissertation by de Groot¹⁹, Chap. 5). Also our theory gives, as we have mentioned before, clear indications of the appearance of the solid state; we hope that it will lead to a better understanding of the present lattice dynamics and its limits, in particular to theories of melting and plasticity.

The most important generalization envisaged is the introduction of quantum mechanics. For there are known several examples of quantum 'liquids': helium II (superfluidity), the substance of nuclei (droplet model), and perhaps also electrons in metals (superconductivity). It is, of course, hopeless to try to understand the abnormal viscosity in liquid helium if one has no theory of viscosity in normal liquids; this gap has now been closed, and we plan to extend our theory of viscosity to quantum liquids.

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ORIGIN OF ERYTHROCYTES

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CONVENTIONAL views on hæmopoiesis may be said to be well founded, in spite of the fact that beliefs in the transformation of precursor elements to definitive blood cells, through a series of specific cell stages, represent, so far as the adult mammal is concerned, dynamic concepts based upon more or less discontinuous observations—in the sense that no one has observed, either *in vitro* or otherwise, the whole process of transformation in adult tissue. Because of this it is not surprising that the facts have been interpreted differently at different times, and that more than one view has been advanced about the development of the blood elements. Equally, it is not surprising that commonly expressed views fail to account for all the known facts. The observations that are reported in this note fall so far outside current generalizations that they seem to lend themselves to a complementary hypothesis of blood formation.

If striated mammalian muscle that has been subjected to trauma is immediately fixed, cytological examination sometimes reveals the presence of very numerous cell elements that appear to constitute a continuous series of transition forms between muscle cells and granulocytes (in the rat, eosinophils in particular). As this observation could be taken to imply that muscle cells were being immediately transformed into leucocytes, as has been described by v. Möllendorff¹ and his school² in the case of fibroblasts, a series of experiments was undertaken in which muscle was first excised and the injury inflicted *ex situ*, in a place chosen arbitrarily. These appear to show that extensive leucocytosis, accompanied by great numbers of transition forms, may occur in a muscle after its removal from the body. The circumstances obviously exclude the possibility of migration of leucocytes from the blood vessels, and also appear to preclude their origin from connective tissue cells, since cytological study of what seem the earliest transition forms suggests much more their derivation from muscle cells. The breakdown of the cellular muscular network results in the appearance of free cellular elements; and nuclear secretion appears to be the main factor responsible for the production of leucocyte granules. The process is so rapid that it has more the character of a cell-catastrophe than that of a slow transformation. The possibility of such a change is implied in Maximow's³ final paper, where it is stated that, in areolar tissue, the transition forms ('Lochkerne') appear only very rarely in specimens in which the possibility of injury during preparation has been minimized so far as possible. This observation obviously implies that rougher treatment stimulates their instantaneous appearance.

Intense secretory activity is not confined to the muscle nuclei of injured muscle. It is a constant finding in a working and anoxic muscle, although in this case it leads not to the production of granules, but to significant changes in the muscle-columns adjacent to the active nuclei. Thus whereas in the resting muscle the sarcomeres are neatly levelled, in activated muscle-columns the nonius-periods appear, and this in places results in a complete release of sarcomeres. This process is always accompanied by

Fig. 1. WORKING MUSCLE (RAT). RELEASE OF SARCOMERES: THOSE LOWER DOWN HAVE THE APPEARANCE OF ERYTHROCYTES

Fig. 2. ISCHÆMIA OF SHORT DURATION (RABBIT). APPARENT ABORTIVE ERYTHROPOIESIS RESULTING FROM THE TRANSFORMATION OF TWO MUSCLE COLUMNS

Fig. 3. MUSCLE DEGENERATION AFTER 5 DAYS (INJURY: FREEZING). APPARENT TRANSFORMATION OF THE WHOLE MUSCLE FIBRE

Fig. 4. WORKING MUSCLE (FROG). ABOVE: APPARENT ORIGIN OF FIVE THROMBOCYTES. BELOW: BUDDING OFF OF AN ERYTHROCYTE NUCLEUS

a striking change in the staining reaction of the sarcomere (best followed in Mallory stained sections), and by a marked increase of their refraction index (Fig. 1). The *A* disks of these sarcomeres, even before release, have a brilliant orange (eosin) or red (Mallory) coloration, contrasting with the pale colour of the alternating *I* disks. These observations can be related to the early findings of Bowman⁴ (Bowman's disks) and to those of Thoma⁵, who found that in certain conditions "the discoidal disintegration begins suddenly in an almost explosive manner". Reconstruction-models reproduced by Aurell and Wohlfart⁶ provide useful information about the disposition of sarcomeres in the striated muscle, and the varying appearances which can be observed (nonius-periods, helicoidal fibres, staircase effect, sphenodes) would seem to constitute different stages in a process of sarcomere release.

The release and transformation of sarcomeres appear to be even more conspicuous in those forms of degeneration of striated muscle which are accompanied by hæmorrhage. The injury causing degeneration brings about a breakdown of the cellular network and a marked slowing down of the secretory process, while the nuclear secretion spreads more diffusely, and is not confined to discrete muscle-columns. As a result, a massive but abortive and stationary transformation appears to occur. In such cases (Figs. 2

and 3) the more or less freed sarcomeres are indistinguishable from erythrocytes. At the same time, isolated and secreting muscle cells appear to undergo an immediate transformation into lymphocytes. Rous⁷ has shown that the number of lymphocytes delivered through the thoracic duct is increased four-fold as a prompt result of muscular activity. He concluded that "the variations caused by muscular exertion . . . are so pronounced as to suggest that the total number of lymphocytes in circulation must be considerably influenced by them. Clinical findings of other observers indicate that this is true. . . ."

All these cytological observations seem to call for a different, or at least an additional, approach to the problem of mammalian hæmopoiesis. Although it is recognized that in the early embryo red blood cells differentiate from primitive mesenchyme, their formation in later stages and in the mammal after birth is assumed to follow a series of fixed stages in their derivation from a nucleated cell in the red marrow. The basis of this genealogy is admittedly incomplete, and in part derives from a study of frank pathological conditions. One of its major difficulties is to explain the fate of the nucleus of the normoblast, in spite of the fact that its lysis (or extrusion) should be an extremely common occurrence.

Nevertheless, without prejudice to this conventional hypothesis, on which they do not touch directly, the observations that are summarized in this note suggest that there may be another source of red cells in the body—striated muscle. They seem to indicate, first, that mammalian red blood elements may be 'cell products (plastids) non-homologous with cells', as was suggested more than fifty years ago on completely different grounds by Minot⁸, and second, that striated muscle, owing to its high and immediate

Fig. 5. COMPARATIVE ANATOMY OF ERYTHROPOIESIS (TENTATIVE SCHEME)

- a Insects (redrawn from Holmgren¹⁴): trophosphongial connexions between the muscle nucleus and sarcosomes.
- b Frog: erythropoiesis (from observation *in vivo*); cf. Fig. 4.
- c Frog: thrombocytopoiesis (from observation *in vivo*).
- d Batrachoseps, tentative drawing based on figures given by Emmel¹⁵.
- e Mammal: lymphocytic hæmal unit } homologous to the amphibian erythrocyte (from photomicrographs).
- f Mammal: endothelial hæmal unit }