in unit time. Owing to the exceedingly high temperatures and to the so-called *Photo-Electric Effect*, the atoms in the stars are dissociated and ionised. Now, by Analogy with perfect gases, the Thermo-dynamical Theory of Gibbs on the equilibrium of gaseous systems may be applied to the electronic dissociation in the stars. Eddington then worked out the formulæ which connect the mass of a star with its radius, its temperature and the quantity of energy which it radiates. For instance the temperature at the centre of the Sun is $4 \cdot 10^{7}$°C. and its pressure, $133 \cdot 10^{7}$ atmospheres. He found also that if the mass of the star is less than 10^{32} gms. the radiation pressure is very small in comparison with that due to matter. On the contrary, if the mass exceeds 10^{35}, the material pressure may be neglected. From astronomical data he constructed his famous *Curve*, which afforded a sufficient test for his theory. But it proved something more.

In the beginning it was believed that Eddington's theories, founded as they are on the Laws of perfect gases, applied only to giant stars. For it seemed inconceivable that the Laws of Boyle and Gay-Lussac could be valid for stars with a density several times that of iron in their interior. But observation showed on the contrary that the properties of gases are to be applied to all the stars (*f.i.*, to *Capella*, whose density equals that of air, and to *Krueger*, sixty times as dense as iron). The thing was astounding. How an explanation was sought and found in the new ideas on the constitution and disintegration of atoms is most interesting, but it far exceeds the limits of the present article.

8. Conclusion

What has been said, however, is sufficient to show the fruitfulness of *Physical Analogy*. By *Analogy*, not only does the scientist systematize his knowledge; he further extends and develops it. *Analogy*, by suggesting the formulation of a Law, will direct the choice of experiments. No doubt, an injudicious use of *Analogy* may lead to a distorted view of nature. Also, merely analogical laws may result in knowledge that is formal and almost nominalistic. Experiment, however, will keep our feet firmly planted on Earth—which will eventually prove to be a spring board enabling the mind to fathom the innermost secrets of the stars.

TONUS IN STRIATED MUSCLE

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THE mechanism by which a state of partial contraction of striated muscle, or tonus, is produced remains enigmatic. The explanation most generally accepted is that a rotational excitement of motor units occurs, one group being released as the next contracts.[1] The excitations would have to be properly timed in order to produce an even and imperceptible contraction as that of tonus. If this were true it would be expected that action potentials led from small aggregates would reveal rotational bursts of impulses. Such a phenomenon has not been capable of demonstration.[2]

Light on the tonic contraction of striated muscle is thrown by studies of similar contraction in unstriated muscle. The chief characteristics of tonic contraction of skeletal muscle are: (1) The metabolism (oxygen consumption and carbon dioxide output) is low when compared with that of muscle when executing movements; it is only about 25 per cent. higher than that of completely paralysed muscle. Posturing muscle is also relatively infatiguable; the deverbrate cat may stand for six days without signs of exhaustion. A small (needle) electrode placed into a muscle unit, shows that it contracts synchronously but responds at a low frequency, *i.e.*, 5-20 per second indicating a correspondingly low rate of discharge from the anterior horn cells.[3] The tension exerted is far smaller than that given by the same muscle when it is stimulated at a high rate (*e.g.*, 100 times per second) through its motor nerve.

Skeletal muscle contains red fibres, rich in sarcoplasm, poorly marked transverse striations and nuclei scattered throughout the substance of the fibres. They contract slowly after a long latency, the duration of contraction being three times that of the more quickly acting and more highly differentiated pale fibres. Red muscles go into tetanus at a low rate of 5 to 8 stimuli per second.[4]

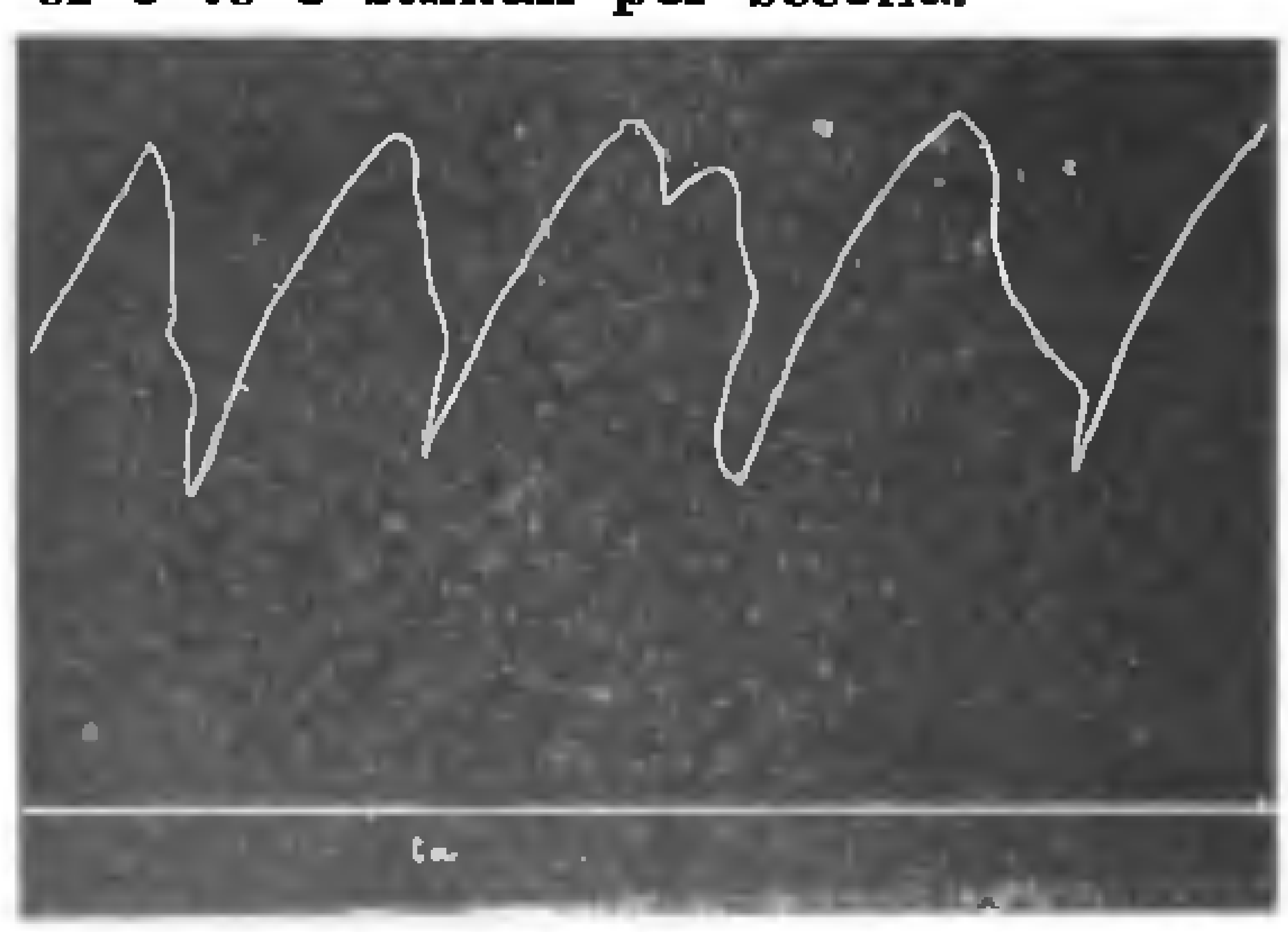

FIG. 1. Mytilus muscle in saline with 0·02 M $CaCl_2$; Barium 0·07 M $BaCl_2$

Now, let us compare the above facts in striated muscle with those in unstriated muscle. Unstriated muscle can be tetanised if stimulated at a much lower frequency than striated muscle; various unstriated muscles in the body may differ in this respect, just as red and pale skeletal fibres. The metabolism of tonic contraction is lower than that of twitch contraction.[5] If *Mytilus muscle* is immersed in a solution containing barium, it passes into a tonic contraction which is maintained by the muscle contracting periodically. Barium, though continuously present in the saline, appears to produce an intermittent stimulation. An interesting feature is that the frequency of stimulation automatically adjusts itself depending upon the slowness of relaxation; as expected the frequency is less, the slower the relaxation. Further the state of the muscle can be changed by varying the calcium concentration of the saline. If the concentration of calcium is high, then the relaxation is more rapid and the frequency greater than if the calcium content is low (Fig. 1).

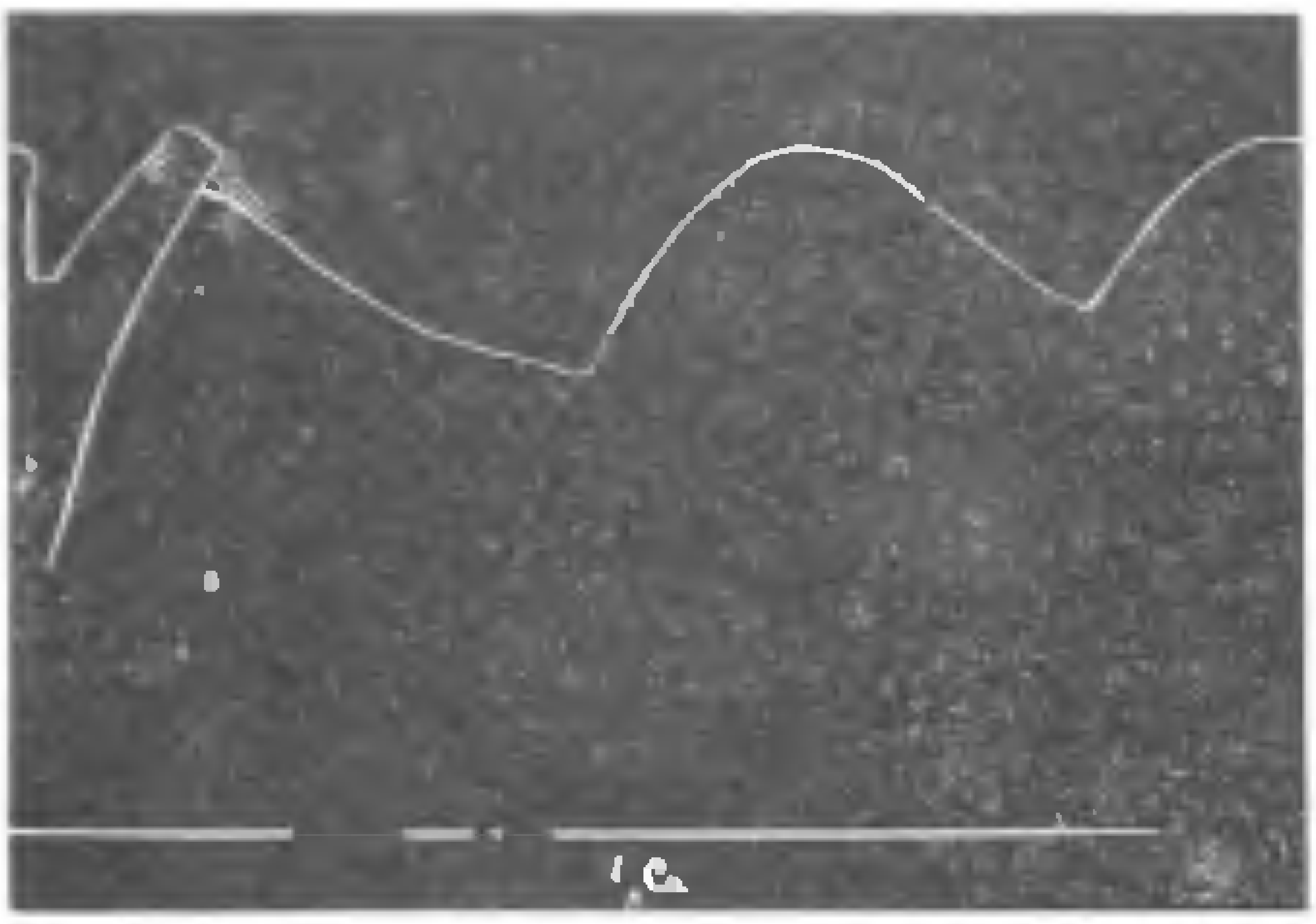

FIG. 2. Same muscle in 0·01 M $CaCl_2$

If the muscle is contracting at a low frequency, it is practically unfatiguable. Thus for tonic contraction, stimulation at a low frequency is required.

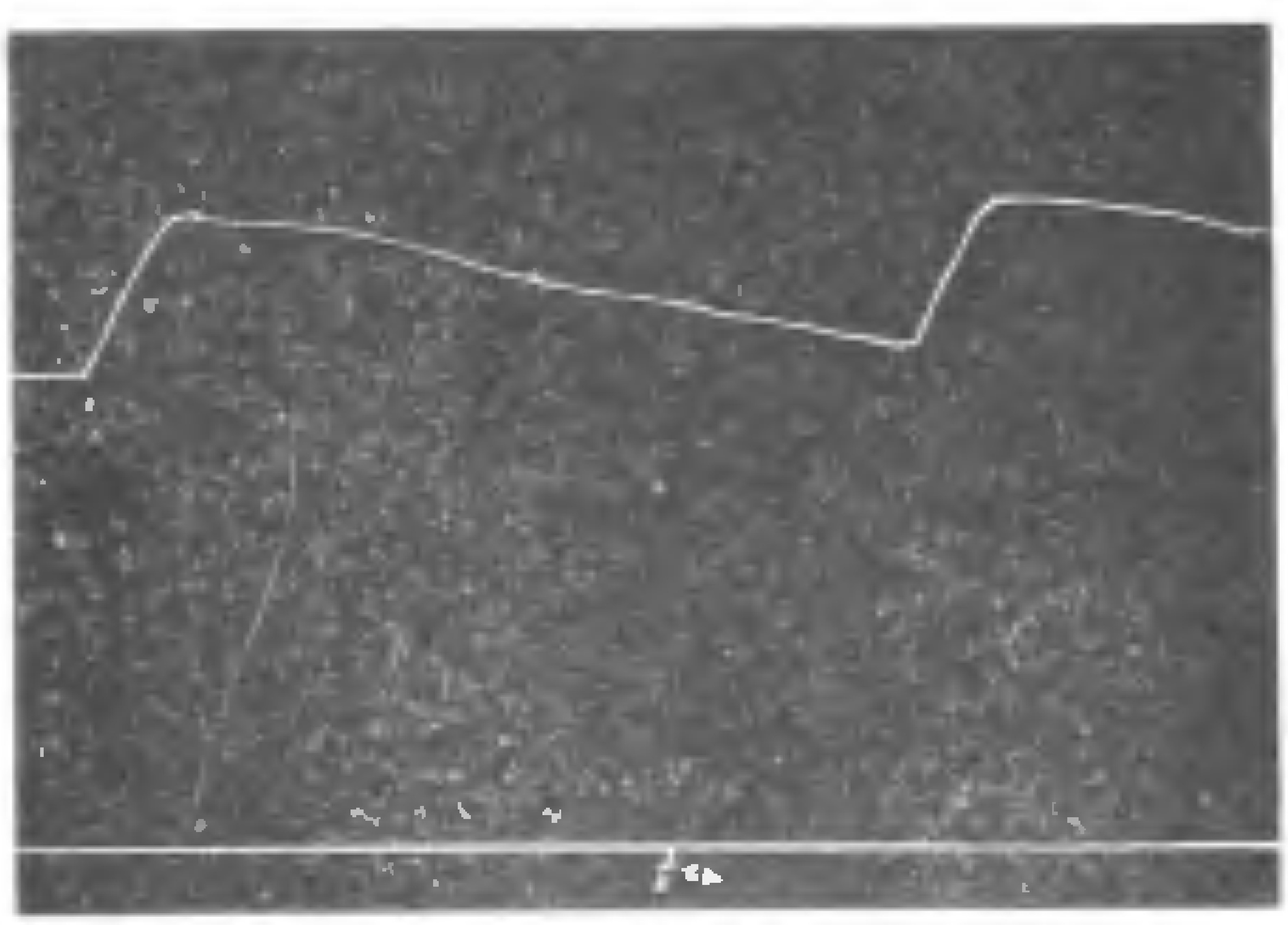

FIG. 3. Same muscle in 0·005 M $CaCl_2$

The above experiments on unstriated muscle show phenomena of tonic contraction which are very similar to those in striated muscle, and suggest that the tonic contractions in the two kinds of muscles are similar. The explanation which has been suggested for the former would, therefore, also apply to the latter.[6] It is probable that in striated muscle the same fibres subserve both twitch and tonic contractions, though differentiation has occurred into

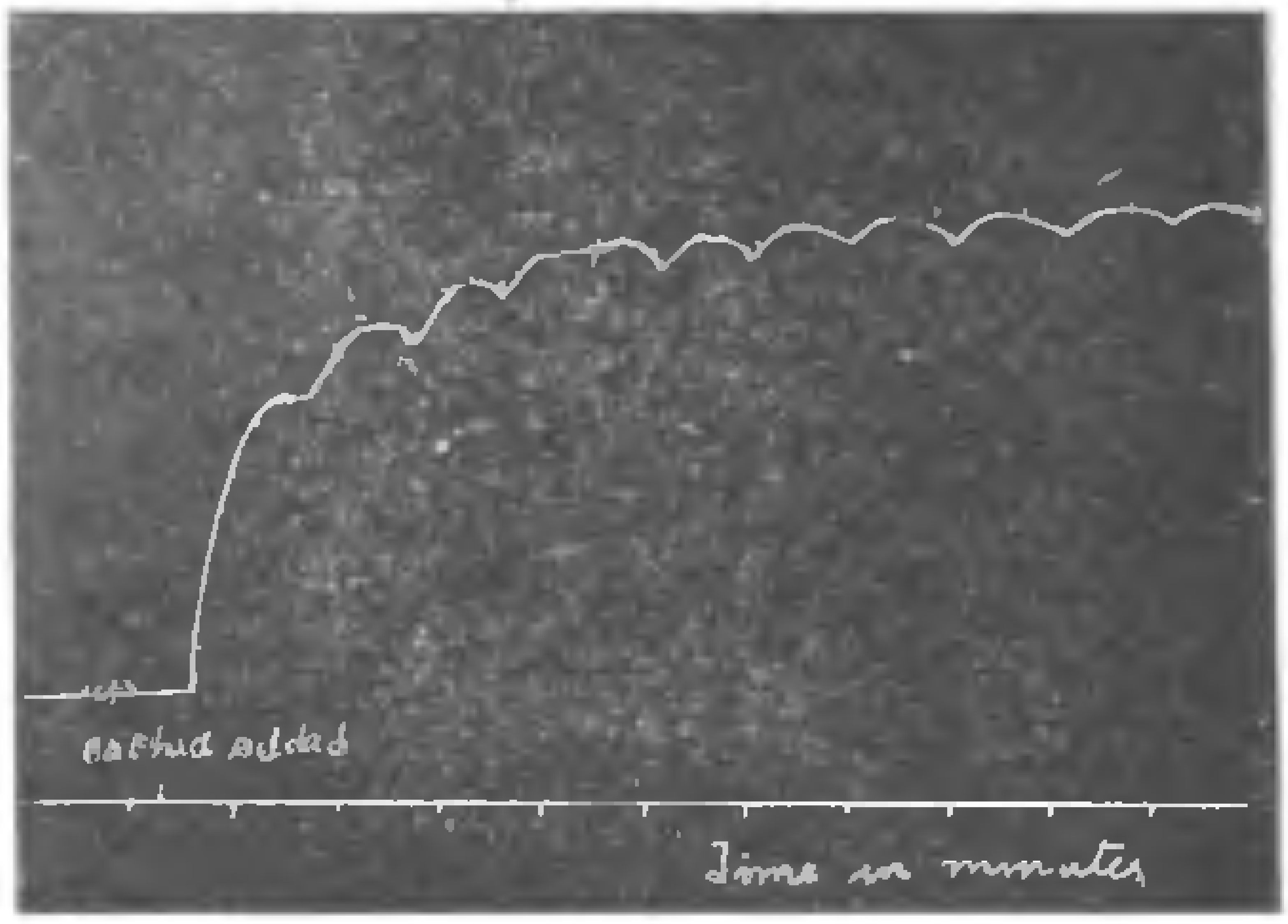

FIG. 4. Another muscle in 0·01 M $Ca Cl_2$

red and pale fibres in skeletal muscles, just as it has occurred in muscle in general into striated and unstriated ones. By some action it is probable that the state of skeletal muscle fibres is varied when they have to contract tonically or quickly. That isolated skeletal muscle is always in a state of partial, though minute contraction has been shown recently.[7] There is no reason why there should not be a variation in the magnitude of this contractile state. The twitch and the tonic contractions may be part of same contraction "spectrum"; as shown, the contractions of cardiac muscle would also fit into the same spectrum.[8] The various components of this "spectrum" may be linked as follows, though there may be some overlapping.

Striated muscle of insects (about 300 contractions/sec.) → slower striated muscle of other animals; pale fibres in twitch contraction (about 100/sec.) → pale fibres in tonic contraction (about 20/sec.) → red fibres (about 10/sec.) → cardiac fibres (about 70/min.) → quickly contracting (about 2/min.).

Unstriated muscle → tonic contraction of some unstriated muscle (about 1/10 min.) → tonic contraction of extremely slowly contracting unstriated muscle (about 1/30-60 min.).

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