THE CONDUCTIVITY OF BLOOD IN COAGULATION

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(Received May 25th, 1907)¹

In a paper on 'Some aspects of adsorption phenomena with especial reference to the action of electrolytes and to the ash constituents of proteins,'² Dr. W. M. Bayliss makes the statement that he has succeeded in showing that a decrease of conductivity of fowl's blood occurs during the process of clotting, which he attributes to the 'disappearance of ions.' This result, he thinks, is what should be expected from our knowledge of the relation of calcium to clotting. In a single experiment he quotes a decrease of conductivity amounting to no less than $18\frac{1}{2}$ per cent. I showed some time ago³ that the conductivity of entire (unclotted) and of defibrinated human blood was practically the same, and that this also was true of plasma, separated from the unclotted blood and of serum from the defibrinated blood. Later on R. T. Frank⁴ confirmed my statement, being unable to detect any sensible change of conductivity in clotting.

It may be that a large series of very careful observations might reveal a slight difference, but it is impossible to suppose that a decrease of $18\frac{1}{2}$ per cent. in the conductivity of blood can be caused by a disappearance of calcium ions in the formation of fibrin, since removal of all the calcium ions in the blood would not produce more than a minute change. It was conceivable that the increased friction due to the jellying of the blood might cause such retardation in the movement of the ions as to account for some part of the difference.

1. Date of Chicago postmark May 14th, 1907.

2. *Bio-Chem. Jour.*, Vol. I, pp. 175-232, 1906.

3. *American Journal of Physiology*, Vol. XIII, p. 139, 1905.

4. *American Journal of Physiology*, Vol. XIV, p. 466.

But this influence could hardly be expected to be great even if, instead of an open felt-work of fibrin threads being formed, the whole plasma set into a homogeneous clot, for it has been shown by Arrhenius¹ and others that the clotting of a gelatin solution containing electrolytes may produce little or no change in its conductivity. And G. N. Stewart² determined that the conductivity change is very slight when egg white or solutions of muscle proteids are coagulated by heat.

It seemed most probable, therefore, that the result of Bayliss was due to some error of observation. One error there must certainly have been, that due to sedimentation of blood during the long interval between the first and the last observation. He expressly states that he did not disturb the U tube in which the blood was contained. Some sedimentation must, therefore, have occurred, and it is a familiar fact to those engaged in conductivity measurements on blood that when sedimentation takes place in a column of blood to any extent the electrical conductivity is decreased, owing to the formation of a badly-conducting layer. It is customary to eliminate this error, which otherwise would entirely vitiate such measurements, by shaking or stirring the blood from time to time, or perhaps constantly by means of a special apparatus. The error can be minimised by making the measurements rapidly.

Another possible source of error might have been the allowing of too little time for the blood to acquire the temperature of the bath before the first measurement. Bayliss says that he permitted the temperature to become 'constant,' but does not state how he assured himself that the temperature of the blood was the same as that of the bath. Blood at 40° C. would require some time to cool to 10.2° C., the temperature of his bath.

If at the first observation the blood was still at an average temperature of 15° C., this would correspond to an apparent decrease of conductivity of not less than 10 per cent. Of course, I do not for a moment assert that Bayliss made any such error as this, but

1. *Zeit. f. physik. Chem.*, Bd. III, page 316, 1892.

2. *Studies from the Physiol. Laboratory of Owens College, Manchester*, 1890, p. 124.

the decrease of $18\frac{1}{2}$ per cent. in the conductivity undoubtedly requires an explanation, and I therefore make the suggestion. With the view of testing the possible magnitude of these errors under similar conditions to those of Bayliss, I made the following experiments. It must be remembered, however, that the rate of sedimentation of different specimens of blood even for two animals of the same species may be notably different.

Experiment I.—Rabbit's defibrinated blood was placed in a glass U tube, immersed in a bath whose temperature remained constant at 7° C. It was left in the bath for thirty minutes. The U tube had been used in many previous experiments, and it was known that in a much shorter time than this the temperature of the blood would be the same as that of the bath. It was then thoroughly stirred by means of a pipette cooled to 7° C., and resistance measurements were taken from time to time. No further stirring of the tube taking place. The interval in minutes from the beginning of the resistance measurements is given in the first column.

Time		Resistance in ohms
0	...	7455
10	...	7520
20	...	7720
30	...	7820
40	...	7880
50	...	7910

Here the resistance increased 455 ohms or 6.1 per cent. in fifty minutes. This is owing to sedimentation, since the stirring up of the blood restores the original resistance. A similar sedimentation will, of course, occur in the entire blood before it clots, and possibly to some extent even after clotting has begun.

Experiment II.—Another specimen of rabbit's defibrinated blood at 35° C. was put into the U tube, which was then immersed in the bath at 7° C. Resistance measurements were begun in five minutes from the time of immersion, the blood not being stirred up throughout the whole series of reading. In the first column intervals from the time of immersion are given in minutes.

Time		Resistance in ohms
5	...	6913
13	...	7297
17	...	7381
32	...	7625
40	...	7703

Here the resistance increased 790 ohms or 11·4 per cent. under the combined influence of sedimentation and fall of temperature. Had the readings been begun earlier, the change would, of course, have been still greater.

Experiment III.—About 7 c.c. of blood was obtained through a cannula in the carotid from a rabbit anaesthetised with ether. The cannula was perfectly cleaned, and had been previously boiled. The blood was shed into a perfectly clean small bottle, which was placed in crushed ice. A second sample was similarly caught, and at once defibrinated. After all the fibrin had been removed it was also placed on ice. Two tubes were filled respectively with unclotted and defibrinated blood, and placed side by side in a bath at 7·5° C. By means of keys either of the tubes could at any time be connected with the Wheatstone bridge. The resistances of the two tubes were measured alternately at intervals. The results are given in the table. The resistance capacities of the two tubes were as 1 : 1·55. Defibrinated blood was placed in the tube of greater resistance. The ratio of the resistance of the tube of unclotted blood to that of defibrinated blood was always less than 1 : 1·55 up to the time when the sedimentation of the blood was stopped by clotting. The reason is that the defibrinated blood was somewhat less rich in corpuscles than the unclotted blood owing to the removal by the fibrin from the defibrinated blood of a larger proportion of corpuscles than serum. It should be further added that the figures of the first and perhaps of the second line are inaccurate, owing to the temperature of the blood at the time of immersion being unknown. That of the entire (unclotted) blood was doubtless at first below that of the bath. In the column marked 'calculated resistance' the actually observed resistances of the defibrinated blood are corrected for the difference of time between the measurements for the entire and defibrinated blood. This correction is, of course, only approximate, especially for the first two or three readings.

Entire blood			Defibrinated blood			Ratio of resistance of entire to defibrinated blood
Time	Resistance	Time	Observed Resistance	Time	Calculated Resistance	
0	6600	3	9200	0	9100	1·37
5	6470	9	9400	5	9266	1·43
15	6480	13	9480	15	9490	1·46
25	6490	24	9590	25	9595	1·47
31	6500	32	9600	31	9592	1·47
40	6570	39	9750	40	9751	1·48
49 ¹	6610	47	9760	49	9778	1·47
57	6610	60	9880	57	9853	1·49
113	6616	92	9970	113	10033	1·45
155	6667	—	—	155	10160	1·46
855 ²	6910	860	12320	855	12345	1·78

1. Clotting occurred at forty-nine minutes.

2. This measurement was made next morning. The increase of resistance is doubtless due to the retraction of the clot in the bend of the tube.

Experiment IV.—In another experiment on rabbit's blood (obtained from a cannula in the abdominal aorta) the resistance of the entire blood increased from 4870 ohms after five minutes' immersion in the bath to 6600 ohms (35·5 per cent.) after forty-two minutes' immersion; and to 8170 ohms (67·7 per cent.) after seventy-five minutes' immersion. At eighty minutes clotting began, the resistance being then 8270 ohms. At eighty-six minutes it was 8300 ohms, and at ninety-five minutes also 8300 ohms, the clot being now of such consistence that no further sedimentation occurred. The temperature of the bath varied from 8·1° C. to 8·3° C. The tube containing the blood was the same as that used for the entire blood in Experiment III, the difference in resistance at one and the same temperature being due to the fact that in Experiment IV the blood was much richer in plasma. Doubtless the greater and more rapid sedimentation was connected with this. The time of clotting of the blood was controlled by examining occasionally a specimen in another tube immersed in the same bath, and also (but only after clotting had begun in the control tube) by inserting a platinum wire into one limb of the tube whose resistance was being measured, and removing a minute drop of the blood. This wire was thoroughly cleaned each time by washing with water and alcohol and then heating in the flame.

Experiment V.—Hen's blood was obtained through a cannula in the carotid, contact of the blood with the tissues being avoided. A portion was run into a small bottle immersed in crushed ice. Another portion was defibrinated, from which a large quantity of fibrin was formed. The two U tubes were filled respectively with the unclotted and the defibrinated blood and immersed in a bath at 8° C.

Entire blood		Defibrinated blood			Calculated Resistance	Ratio of resistance of entire to defibrinated blood
Time	Resistance	Time	Observed Resistance	Time		
12	4835	7	6890	12	6926	1·41
22	4860	25	7020	23	6998	1·43
30	4882	35	7045	30	7032	1·45
49 ¹	4900	46	7065	49	7071	1·44
55	5100	—	—	—	—	—

1. Clotting occurred before forty-nine minutes.

Experiment VI.—In this experiment hen's blood was also used, but a small portion of muscle was dropped into the U tube to cause coagulation. Temperature of the bath 7° C.

Entire blood		Defibrinated blood				Ratio of resistance of entire to defibrinated blood
Time	Resistance	Time	Observed Resistance	Time	Calculated Resistance	
15	4610	5	6230	15	6360	1'37
20	4680	10	6250	20	6428	1'39
25 ¹	4710	15	6360	25	6496	1'38
35	4715	34	6620	35	6634	1'40
115	4725	109	7130	115	7170	1'51

I have to thank Dr. G. N. Stewart for calling my attention to the possible sources of error in such observations, and for suggesting methods for their elimination.

1. Clotting occurred at twenty-five minutes.