An Empirical Relationship between Intrinsic Viscosity and Frictional Ratio

Einstein's relationship:

$$\eta = \eta_0 (1 + 2.5\, G);$$

in which η and η_0 represent the viscosities of a suspension and of the dispersion medium respectively and G the volume of the suspended particles/100 ml was, for many years, assumed to be correct. This was mainly due to its confirmation by Eirich and Goldschmid[1] and by Eirich, Bunzl and Margaretha[2].

These authors measured the increase of viscosity by the addition of tiny glass spheres to media of high density into which the glass spheres did not settle. Einstein's equation was also confirmed in a similar manner by Cheng and Schachman[3] who also used microspheres of known diameter. In both instances use was made of particles which were very large when compared to protein molecules. Such particles would show very limited Brownian movement. When the equation of Einstein was tested on solutions of proteins of known molecular weights and frictional ratios, it was observed that the relationship required considerable correction to be valid.

The frictional constant f/f_0 of a protein is a function of hydration and of its departure from the spherical and compact state. Similarly the intrinsic viscosity $[\eta]$ of a protein is dependent upon these properties. If a relationship could be found between f/f_0 and $[\eta]$, the value of $[\eta]$ could be obtained when $f/f_0 = 1$, i.e. the value for an unhydrated molecule of spherical and compact state and the numerical in Einstein's equation could be verified.

The Table shows data of $[\eta]$ and f/f_0 for a number of proteinaceous and low molecular weight substances. The data were obtained from the literature and from the author's unpublished work. In the fourth column are tabulated the logarithms of the quotient of the intrinsic viscosity and the partial specific volumes V.

Log $[\eta]/V$ and f/f_0 values for various proteinaceous and low molecular weight substances

Substance	$[\eta]$cc/g	Vcc/g	log $[\eta]/V$	f/f_0
Ribonuclease	3.30[4]	0.728	0.656	1.14[5] 1.04[5]
Whale myoglobin	3.30[6]	0.738	0.651	1.14 1.11[7]
Ovalbumin	3.90[8]	0.748	0.717	1.18
Catalase	3.90[9]	0.73	0.727	1.25
Jasus lalandii hemocyanin	4.01[18]	0.738	0.743	1.23
Amandin	4.40[8]	0.746	0.833	1.28[10]
Southern bean mosaic virus	4.40[11]	0.700[11]	0.798	1.25[11]
Fibrinogen	27.00[12]	0.710	1.580	2.34[13]
Trypomyosin	52.00[14]	0.740	1.847	3.10[15]
Myosin	217.00[16]	0.728	2.47	3.53[16] 4.0[17]
Sucrose	2.43[19]	0.630	0.586	0.87[a]
Citric acid	1.74[18]	0.648	0.426	0.77
Glucose	2.50[8]	0.629	0.586	1.00
Glycerol	2.60[19]	0.800	0.481	0.86
Glycine	1.49[8]	0.625	0.380	0.835
Urea	0.15[8]	0.741	1.301	0.638
Pentaerythrite	2.8[20]	0.71	0.5955	0.937

[a] The f/f_0 values of the low molecular weight substances were calculated from diffusion coefficients D, molecular weights M, and from partial specific volumes V according to equation:

$$D = (k/M\,V)^{1/3}\, f_0/f$$

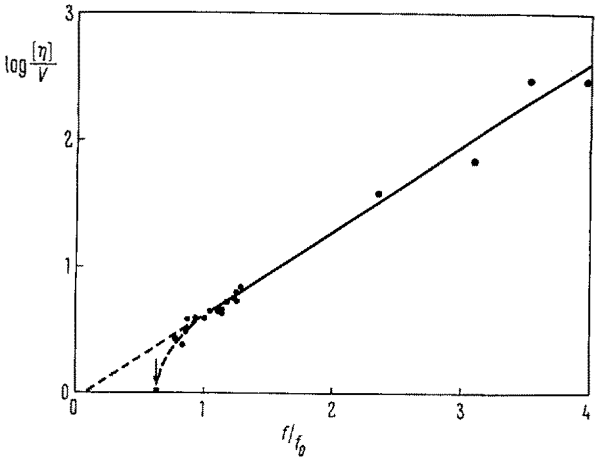
where $k = 2.41 \times 10^{-14}$.

The data in the Table are presented graphically in the Figure. It will be noted that the relationship between log $[\eta]/V$ and f/f_0 is approximately linear above $f/f_0 = 1$ and that the value of log $[\eta]/V$ for a spherical unhydrated molecule may be obtained accurately by interpolation at $f/f_0 = 1$. The value obtained thus equals 0.61 from which $[\eta]/V = 4.1$ followed.

Einstein's equation should thus be modified to:

$$\eta = \eta_0 (1 + 4.1\, G),$$

or $[\eta] = 4.1\, V$ in terms of intrinsic viscosity and partial specific volume. The numerical 4.1 is in good agreement with the value 4.05 previously obtained by Polson[21] from diffusion measurements on proteins. The value obtained above is approximately 10% lower than the value calculated by Hatcheck[22] for the intrinsic viscosity of spherical particles.



Graph showing the relationship between log$[\eta]/V$ and f/f_0 for high ($f/f_0 > 1$) and low ($f/f_0 < 1$) molecular weight substances. The arrow indicates that the value for urea is much less than 0.

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It has been observed that a number of ultracentrifugally homonegeous proteins investigated in our laboratory showed sedimentation coefficients which were dependent upon the rotor velocity at which they were determined (POLSON)[23]. Thus it was found that the 3 proteins γ-globulin, ovalbumin and hemocyanin of Jasus lalandii when spun at rotor velocities below 20,000 rpm showed sedimentation coefficients which were approximately 11% higher than those obtained at velocities above 40,000 rpm. If this is a general phenomenon with proteins, it would indicate that their molecular weights, as determined by the velocity method, need revision. A consequence of this would be that the f/f_0 values of proteins would become smaller than that at which they are quoted, which would result in the numerical 4.1 in the empirical equation moving closer to HATCHECK's value of 4.5 and further away from Einstein's figure of 2.5.

An interesting conclusion may be drawn from the Figure. By extending the straight portion of the graph into the region below $f/f_0 = 1$ it would appear that the abscissa is intersected at a position very close to the origin or approximately $f/f_0 = 0.06$. Considering the experimental error involved and the approximate correctness of the slope of the straight line, it may be concluded that the line could justifiably pass through the origin. The simple empirical relationship $f/f_0 = {}^1/_{0.61} \log [\eta]/V$ appears to represent a true relationship at $f/f_0 = 1$ and > 1 between the frictional ratio, intrinsic viscosity and partial specific volume.

The empirical relationship fails to apply to substances of which frictional ratios f/f_0 are less than 0.90. Values below $f/f_0 = 1$ are shown by substances of low molecular weight which have molecular volumes of the same order of magnitude as those of the dispersion medium. Such substances have intrinsic viscosities which decrease rapidly with decreasing molecular volume to vanish when the molecular volume of the dispersion medium is reached (POLSON)[24], hence $\log [\eta]/V = 0$ when f/f_0 is still finite[25].

Zusammenfassung. Es wurde ein empirisches Verhältnis zwischen Reibungskonstante und «intrinsic» Viskosität abgeleitet, woraus sich eine neue Konstante für die Einsteinsche Gleichung ergab.

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Effect of Castration and Testosterone Administration on the Noradrenaline Content of the Vas Deferens and the Seminal Vesicle of the Guinea-Pig

The large amounts of noradrenaline found in the internal accessory male organs of the guinea-pig[1,2], are due to an unusually rich supply of adrenergic nerves, emanating from short adrenergic neurons, with their cell bodies located close to the target organs[3,4]. The same pattern of innervation is present also in other species[2,4]. (For further references c.f. SJÖSTRAND 1965[2]).

Since the development and size of the accessory male genital organs is dependent on the presence of androgenic hormones, it appeared to be of interest to study the effect of testosterone administration and castration on the noradrenaline content of the vas deferens and the seminal vesicle of guinea-pig, and thus obtain some quantitative data on the effect of androgens on the adrenergic innervation of internal male genital organs.

Material and methods. Young guinea-pigs having an initial weight of about 300 g were used. They were divided in 5 groups with 4–6 animals in each group. One group served as untreated control group. The animals of 2 other groups were castrated 28 days before killing. The guinea-pigs of one of these castrated groups and those of another non-castrated group received the following injections i.m.: 16 days before killing each animal received 10 mg testosterone propionate, 40 mg testosterone valeriate and 75 mg testosterone undecylenate oil solution (0.5 ml Triolandren ® solution). On the 8th, 6th, 4th and 2nd day before killing each animal received 1 mg testosterone propionate in oil solution (Perandren ®). These groups are referred to as 'testosterone low dose'. The animals of the last group received the following injections i.m.: 16 days before killing each animal received 30 mg testosterone propionate, 120 mg testosterone valeriate and 225 mg testosterone undecylenate (1.5 ml Triolandren ® solution). On the 8th, 6th, 4th and 2nd day before killing each guinea-pig was given 3 mg testosterone propionate (Perandren ®) ('testosterone hight dose'). The animals in all groups received the same care and food during the 4 weeks the experiment lasted. All animals were sacrificed by a blow on the head. The vas deferens and the seminal vesicle were taken out, cleaned and their contents were squeezed out. The noradrenaline content of the organs was determined according to EULER and LISHAJKO[5] in the same manner as described earlier[1,2]. The noradrenaline is expressed as hydrochloride. All data obtained from the 'experimental' groups are compared with those of the control group and their significance tested by the *t*-test (FISHER[6]).

Results. The results are shown in the Table.

Discussion and conclusions. From the present study on the guinea-pig it seems evident that castration increases the noradrenaline concentration of the vas deferens and the seminal vesicle, but has no certain effect on the total amount of noradrenaline in these organs. On the other hand, large doses of testosterone tend to decrease the

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