ART. VIII.—*The Strength and Elasticity of Spider Thread*;
by J. R. BENTON, PH.D.

THE writer of this note happened to notice a spider thread of such extraordinary thickness and length (0.01^{cm} in diameter; 2.5^{m} long) as to suggest the idea of measuring its physical properties, since this could easily be done with the thread in question, though it would be exceedingly difficult with spider threads of the usual size.

The results may be of interest for the following reasons: (1) as furnishing a test of the popular idea that spider threads are composed of a substance of extraordinarily great strength; (2) on account of the occasional technical application of spider threads in the reticules of scientific instruments; and (3) because the material of the thread, in its chemical nature, is placed among the proteids, which usually have peculiar mechanical properties. On account of the great complexity of chemical structure of the proteids, their physical properties may be especially useful in determining their relationships with one another. In the present instance, the mechanical properties of spider thread may furnish ground for deciding whether or not its material is identical with silk, as is sometimes asserted.

A spider thread, as is well known, is not usually composed of a single fiber, but of a number of fibers adhering together more or less closely. In the thread used for the present study, the number of component fibers was very large. It was not feasible to count them directly; but single fibers, when separated from the main thread, could be seen to have a diameter less than one-twentieth of that of the main thread. This would indicate several hundred fibers in the main thread, if it can be assumed that all of the component fibers have the same size. The component fibers appeared to adhere together only very loosely; at some places bundles of them were distinctly separate from the rest of the thread. Under such circumstances the apparent cross-section of the thread varied greatly from point to point. The true cross-section must be known in order to determine the mechanical properties of the material; and as it was not feasible under these circumstances to ascertain the true cross-section, the thread was twisted, so as to bring all of the component fibers into one compact mass. The twist applied amounted to three revolutions for each centimeter of length, and it resulted in bringing the fibers together into a cross-section of fairly perfect circularity. The diameter, as measured by a micrometer microscope, varied from point to point between the limits $.0076^{\text{cm}}$ and $.0103^{\text{cm}}$.

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Tensile Strength.—The following results were obtained for the tensile strength, or stress to produce rupture, the thread having been twisted as described :

Number of trial	Load at rupture in grams weight	Cross-section at point of rupture	Stress at rupture	
			Dynes per cm ²	Pounds per sq. in.
1	40	$5.28 \times 10^{-5} \text{cm}^2$	7.4×10^8	11000
2	82	5.28	15.2	22000
3	85	4.55	18.3	27000
4	85	4.55	18.3	27000
5	88	4.55	18.9	28000
6	98	4.95	19.4	28000
Final value: (Mean of trials 2, 3, 4, 5, and 6)			18.0×10^8	26200

It would seem justifiable to assume that the first trial, giving a value less than half the mean of the other, represents some anomalous condition (such as a flaw in the material). It is accordingly rejected.

It appears then that the material of this thread possesses quite a high tensile strength, about double that of most kinds of wood (the value for pine being about 10,000 and for other woods ranging between 6,000 and 23,000 pounds per square inch).

Variations in Length.—The length of the thread was found to vary irregularly from day to day, the stretching force being constant. This was probably due to absorption of moisture, but was not definitely investigated.

Elastic After-effect.—If the stretching force was changed, the thread stretched (or contracted); but the strain so produced did not at once assume a constant value, but gradually varied. Thus in one set of experiments, the stress was increased by 5×10^7 dynes per cm² (730 pounds per square inch) or 1/36 of the mean breaking strength, and readings taken at intervals of 30 seconds after applying the load gave the following values for the strain (mean of three trials):

·00200
·00203
·00207
·00210
·00218

Upon removing the load as soon as these readings were taken, the following values of the strain were observed at intervals of 30 seconds:

·00048
·00040
·00037
·00034
·00029

Similar, but much less distinct, effects were observed when the change in stress was only half as great.

On account of the hygroscopic properties of the substance it was not feasible to follow these changes over any great length of time.

Young's Modulus.—In view of the variations of strain just described, it is clear that any value obtained for Young's modulus, or the ratio of stress to the corresponding strain, must involve some arbitrariness depending upon the time when the strain is observed. A similar situation exists for most other substances, however, though it is not usually emphasized in publications as much as, in the writer's opinion, it ought to be. Most (if not all) substances exhibit some elastic after-effect after any change of stress, even when the change of stress is very small. It is customary, in computing the modulus of elasticity, to use the value of the strain observed immediately after changing the stress. The result obtained in this way will be approximately the same as if any later value of the strain were used, the approximation being more or less good according as the elastic after-effect is more or less small.

In the present experiments a load was applied long enough (about three minutes) to obtain five readings for the increase in length; then the load was removed, and five readings were immediately taken. The change in length, as determined from the mean of the five readings with the load, and the mean of the five readings after removing the load, was made the basis of computation for Young's modulus.

The first experiments were made with a thread 6.2^{cm} long and 6.19×10^{-5} cm² in mean cross-section. The mean of ten experiments gave for Young's modulus 3.27×10^{10} dynes per cm² (480,000 pounds per square inch), the different determinations varying from 2.98 to 3.62×10^{10} dynes per cm². The change in stress employed was 2.5×10^7 dynes per cm². With larger change in stress the after-effects were so great as to prevent proper determination of the modulus.

Ten experiments were also made with another piece of the thread, 16.5^{cm} long, and 5.30×10^{-5} cm² in mean cross-section, twisted with a specific twist of three revolutions per centimeter of length, the same range of stress being used. They gave a mean value for Young's modulus of 2.70×10^{10} dynes per cm² (390,000 pounds per square inch), the extremes being 2.10 and 3.29×10^{10} dynes per cm².

Adopting as the final value for Young's modulus 3.0×10^{10} dynes per cm², it appears that the material of the spider thread is, like most organic materials, much more stretchy than the

metals (modulus about 10^{12}), but does not at all approach such a substance as rubber (modulus about 10^9 dynes per cm^2).

Elongation at rupture amounted to about 20 per cent of the original length of the thread.

The thread showed a distinct elasticity of torsion; but in view of its complex structure, data on torsion can not have any very definite significance, and accordingly are not presented.

Specific Gravity.—A 10^{cm} length of the thread, of mean cross-section $5 \times 10^{-5} \text{ cm}^2$, weighed 0.33^{mg} , which gives for the specific gravity, 0.66.

Comparison with Silk Fibers.—The mechanical properties of silk fibers have been studied by Beaulard,* who found for the tensile strength 2.85×10^8 dynes per cm^2 , and for Young's modulus 6.50×10^{10} dynes per cm^2 . As these values differ from those for the spider thread by amounts greater than would be accounted for by experimental errors, it seems probable that the material of the spider thread is different from silk.

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* F. Beaulard: *Comptes rendus*, cxxxv, pp. 623-626, 1902; *Journal de physique*, ii, 785-795, 1903; quoted in *Science Abstracts*, 1903, p. 129, and 1904, p. 137.