Comparative Studies on the Rate of Circumnutation of Some Flowering Plants.

By Elizabeth A. Simons.

DURING the spring term of session 1897-98 the Senior and Post-Graduate students of the Botanical Department began, under the direction of Professor Macfarlane, a series of experiments on the circumnutation of stems, for comparison of the results with those obtained by Darwin* and more recently in the Botanic Garden of the University by Dr. A. Schively.†

The writer was asked to continue and extend these results, for five plants specially recorded by Darwin. These are *Convolvulus Sepium*, *Phaseolus vulgaris*, *Lonicera brachypoda*, (*L. japonica*), *Wistaria chinensis*, and *Humulus Lupulus*. Marks were made at frequent time-intervals on a plate of glass placed directly above the circumnutating tip, and permanent graphic records have been prepared from them. The tables appended to this paper have been compiled from these.

The shoots were carefully tied to a support, and in most cases three internodes were left free. The records extended over a period of about six months, and thus included times when the sun gave considerable differences of light intensity and of temperature. In this paper no account is taken of light intensity, though data are being gathered which indicate that this is a factor in circumnutation, as is also the relative hygrometric condition of the atmosphere. It is somewhat unfortunate that few details are given by Darwin as to environmental conditions, but the writer regards the relatively higher temperature that prevailed during her studies as the main factor

* Power of Movement in Plants.

† Bot. Contrib. Univ. Penn. Vol. I.

in producing the accelerated movements, as compared with those obtained by Darwin.

Convolvulus Sepium.—Young actively growing shoots of this species were observed in the greenhouses of the Botanic Garden for four days and nights by members of the class in continuous relays. Note was made of the temperature of the house, and of the prevailing atmospheric conditions outside.

A dark sky and low temperature (15 C.–19.5 C.) gave discouraging figures for the first three days. The quickest time made during the period was 1 hour 45 minutes; the longest, 4 hours 15 minutes; average, 2 hours 40 minutes. The twenty-fifth of the month was a clear day and the temperature ranged from 15.5 C. to 33.5 C., resulting once in a circumnutation in 57 minutes: the longest took 3 hours; the average time for the day was 1 hour 53¼ minutes. The behavior of the plants with respect to light and temperature would point to Darwin's conclusion, that both are important factors in plant movement.

The rainy days afforded no good opportunity for observation of periodicity of growth, but the clear day caused an acceleration of movement from 8.05 a. m. till 2.30 p. m. in one case, and from 9 a. m. till 4.32 p. m. in another, the successive circles being:

SPECIMEN 1.

First circle	2 hours 30 minutes.
Second circle	1 hour 45 "
Third circle	1 " 25 "

SPECIMEN 2.

First circle	2 hours.
Second circle	1 hour 50 minutes.
Third circle	1 " 15 "
Fourth circle	1 " 10 "
Fifth circle	1 " 2 "
Sixth circle	57 "

The night circumnutations were longer than the average daily ones.

Later in the season, on July 18, August 8 and 15, experiments were performed on shoots of *Convolvulus Sepium* growing in the garden. The plant spread itself, for the most part, along the ground, slender branches, now and then, standing upright and exhibiting a tendency to climb. The times of revolution were as shown in the table appended, the shortest, 1 hour 11 minutes, being longer than the spring time of 57 minutes. This plant produces two distinct types of stem, the twining and the prostrate. The latter are of a darker color, more woody, thicker and have stronger tips. Two of these were tied to a support and watched from 8.30 till 1. There was no perceptible movement, later a slight one. Nothing further took place before 2.35 p. m., when observation ceased. Three days later no evidence of ability to climb could be noticed, the stems having been left tied to their supports.

Humulus Lupulus.—Winter buds of the Hop were transplanted and formed vigorous shoots by February 9, when circumnutation movements were observed during two days (two distinct plants used), with the appended results.

The periodicity of growth was not so marked in this case, but gave indication of afternoon acceleration, as will be seen by reference to the table.

Darwin's shortest time for the Hop was 2 hours 8 minutes, during what he called "hot weather." Our plants were first observed in late winter when 1 hour 5 minutes was the shortest period. On a hot day (July 15) tips of a plant growing in the garden were protected from wind, supported, and watched under glass; the time 1 hour 40 minutes, was obtained. Another tip made a circle in 2 hours 35 minutes, when it seemed to be burnt. On August 16, another tip was tried, with the result 2 hours 14 minutes. Casually observed, the tips do not seem inclined to grow vigorously in the hot weather. The quick spring movements confirm this.

Lonicera brachypoda and *Phaseolus vulgaris* were used in class

work, but insufficient data were collected from which to generalize. Those obtained have been incorporated with the writer's later observations. The Scarlet Runner studied was a seedling, the *Lonicera* had grown from a cut-back plant.

A fine specimen of *Lonicera brachypoda* growing in the garden, and having no chance to climb, bore numerous healthy tips. It was surrounded by a box, whose top and bottom had been removed, as well as some boards from the side. This was partly covered by glass, but plenty of air was allowed entrance. Some of the shoots were so vigorous that they needed no support; others were long stems and had to be supported.

On July 18, no glass was used, but record was kept by marks on rods of wood laid above the tip. The movements then obtained were the slowest recorded, and it is likely that the extra protection from wind and retention of heat by the glass cover, produced the quicker movements of August 15.

When watched in the greenhouse, *Lonicera* showed itself extremely sensitive to heat; high temperature invariably being associated with rapid movement.

Our shortest time is 1 hour 43 minutes; Darwin obtained 7 hours 30 minutes. He makes no mention of temperature beyond saying "a warm room in the house." The full results obtained are appended.

Scarlet Runner seedlings were used in the greenhouse for experiment. The panes of the house were whitewashed, and the intensity of light thus diminished. The tips never needed support, young ones being invariably chosen. The results as appended show that the shortest time obtained with this species was 1 hour. On April 5, we obtained 1 hour 20 minutes, as compared with Darwin's observation on May 2 —1 hour 55 minutes.

Wisteria chinensis.—On July 11, young sprouts of this species were found in good condition on a cut-back plant in the greenhouse; one that had been entirely shorn of branches

and leaves. Darwin worked on this species in a greenhouse from May 13 till May 25, and obtained as his shortest time, 2 hours 5 minutes, with an average of 2 hours 50½ minutes. By taking advantage of every fresh sprout as it began to reach for a support, the results appended were obtained.

Growing in a protected corner of the garden was another *Wisteria*, with long, strong stems, of which three were unsupported. On August 18, these were gently secured to stakes, two of them hanging just as on the vine, being secured at one point to a stick to insure against wind interference, the third being tied upright with about nine inches free. This began its twisting in that position, but gradually became horizontal from the point of attachment. Apparatus for marking was set up and the following results obtained. All the stems were exposed to direct sunlight except for a short time, when they passed through an arc shaded by the plant itself.

The shortest time obtained was 2 hours, the average of all observations 2 hours 15⅜ minutes.

As to the time of day when circumnutation is most rapid, the following diagram was made from the foregoing records of the five species examined. The temperature recorded for a circumnutation represents the average for the hours between which the circle was made. The temperature records are suggestive, those during the shortest circumnutations ranging from 25.5 C. to 36.5 C.; of the longest, 15.5 C. to 30.5 C.

From the table it will be noticed that of the 31 quick twinings, 22 are in the afternoon. Looking at the list of long circumnutations 8 of 18 are in the afternoon. But a more detailed analysis brings out some interesting results, that correspond very closely with those given by Dr. Schively in the paper already cited (pp. 296–97). The following statement is there made regarding periodicity of circumnutation. "Beginning with the early hours of morning, there is a gradual acceleration until 11 or 11.30 a. m. The greatest rapidity occurs from this time until 2 or even 3 p. m. After that time

there is a gradual decrease in the rate, until several hours after midnight. The maximum period may be much extended, beginning earlier and continuing until 4 or perhaps 4.30 p. m., if the day is very hot." From the tables compiled by the writer, the following comparison of four-hour periods is obtained. The agreement of these statistics drawn from five species of plant, with the statement above quoted need merely be noted.

Between the hours	were performed
8—12 a. m	11 circumnutations.
9— 1 p. m	12 "
10— 2 "	11 "
11— 3 "	16 "
12— 4 "	19 "
1— 5 "	23 "
2— 6 "	18 "

When the experiments were begun, it was thought that under our comparatively bright sky and warmer temperatures, as contrasted with the atmospheric surroundings of England, circumnutations might be performed more rapidly than in the shortest time-limits given by Darwin. Subjoined is a comparison of the two sets of results:

AT DARWIN'S HOME.

Phaseolus.	(Greenhouse, May 2)	1 h. 55 m.
Humulus.	("Hot weather")	2 h. 8 m.
Convolvulus.		1 h. 42 m.
Lonicera.	(House, April 3)	7 h. 30 m.
Wisteria.	May 16	2 h. 5 m.

AT UNIVERSITY OF PENNSYLVANIA.

Phaseolus.	(Greenhouse,	April 5)	1 h. 20 m.
"	"	July 18	1 h.
Humulus.	"	February 9	1 h. 5 m.
Convolvulus.	"	March 25	57 m.
Lonicera.		April 5	2 h. 48 m.
"		August 15	1 h. 43 m.
Wisteria.		July 11	2 h.