Electric, elastic and magnetic properties of Spanish moss

Lindsey Channels
Department of Physics, Bowling Green State University, Bowling Green, OH 43402 and National High Magnetic Field Laboratory, Tallahassee, FL 32310
(Dated: July 28, 2005)

Several experiments were performed on Spanish moss, treating it as a physical sample rather than a biological one. These tests include resistivity, elasticity, dielectric, and spectroscopy. The results show Spanish moss is a very durable, insulating material, with a resistivity between 4.8 and 17.7 Ω.m. The elasticity test reveals that a small branch of Spanish moss can hold a mass of about 100 grams before breaking. Strong manganese lines came up in the EPR, and iron III started to emerge as the temperature decreased, with a large peak around 145 Kelvin.

I. INTRODUCTION

Spanish moss, *Tillandsia usneoides*, is a member of the bromeliad family, which consists of plants whose leaves are tightly overlapping to store water, as shown in FIG. FIG. 1 and 2. These leaves, which resemble scales, have tiny white hairs known as trichomes that transfer moisture from the surface of the leaf to the inside of the plant. Spanish moss is an epiphyte, meaning that it grows on other plants without being parasitic. This type of plant is also referred to as an air plant since it does not root into soil [1, 2]. It reproduces when the flowers bloom and each release anywhere from 2 to 23 tiny fibrous pods that attach to trees without burrowing into them. The small roots stick to the tree bark, but as the plant develops, the roots will dry out (FIG. 3).

Spanish moss will continue to grow without its roots, and the leaves will absorb moisture and nutrients from the air, as well as water deposited on the surface of the host tree. Typically, the moss will grow as one strand, and sprouting a few branches on alternating sides in nodes (FIG. 4). The length between each of these nodes indicates the plant's response to its habitat, how well its living conditions have been. At some point in this growth, the strand will end with a single flower, and a new strand will start one node above [2].

Using plants for energy could be an ideal alternative to the current solar cells, since our solar cells are capable of only using on average, about ten percent of the sun's energy [3]. Plants are much more efficient, using all of the sun's energy, and storing it for later use. Spanish moss is very abundant in the southern United States and Central American countries. It requires no attention from humans, and easily reproduces and spreads its existing plants during strong winds and storms. The tests in this report will show basic physical properties of Spanish moss, being potentially useful for future studies using this plant as a regenerating energy source.

FIG. 1: Spanish moss in front of National High Magnetic Field Laboratory's 45 Tesla hybrid magnet on a live Oak tree.

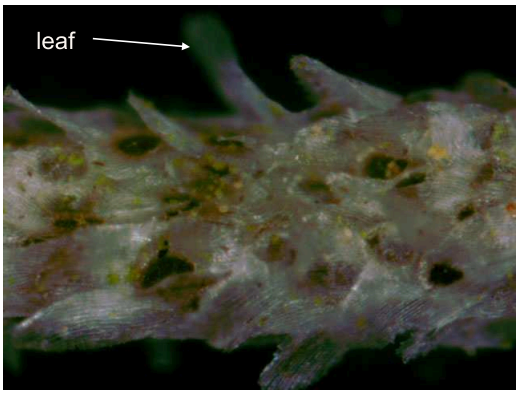

FIG. 2: Spanish moss through microscope, approximate diameter is 80 micrometers.

FIG. 3: Roots of new Spanish moss plant, total height is 1.5 centimeters.

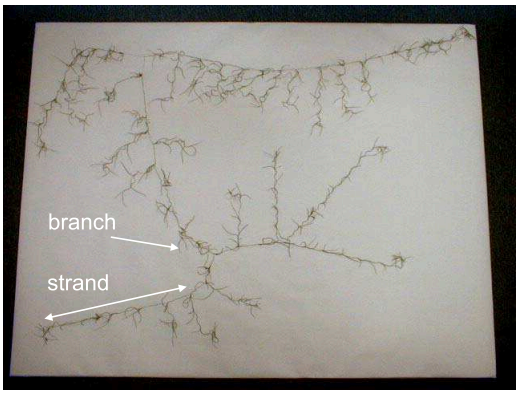

FIG. 4: Spanish moss spread out on paper, approximately 2.5 x 3.5 feet.

II. EXPERIMENTAL METHODS

A. Electrical transport

Using fresh samples of Spanish moss, several methods to test resistance were performed. Data was taken with a Keithley 220 programmable current source and 5617A electrometer/high resistance meter. The first method involved small gold wires attached to the moss with a small amount of silver paste as a conductor. Because the leaves on the moss protected the actual surface of the plant so well, the silver paste was unable to make contact, giving a very unstable reading of voltage. Using small amounts of salt water on the connection points allowed for a more stable reading of voltage.

Placing a branch of Spanish moss across a circuit board enabled the use of a less delicate approach for the resistance test. Small amounts of the conducting polymer Pedot was used to connect the Spanish moss to the four connection points on the circuit board. The Pedot is quickly absorbed by the plant's leaves, so non-conductive grease was used as a barrier in-between Pedot applications. The same method is used to find the resistance of a pine needle.

B. Elasticity

Spanish moss appears to be a durable plant. When holding the ends of a tiny branch, and pulling gently, the moss will stretch easily before breaking. An elasticity test is performed to determine the amount of weight necessary for the Spanish moss to break, and to measure the displacement as the plant stretches with each addition of weight. A simple apparatus was used to vertically hang a branch of Spanish moss in front of a microscope. Using an eyepiece with markings in micrometers, the displacement was measured from a marked point on the branch. Nuts and bolts were individually measured in grams and carefully placed in a small basket attached to the bottom of the Spanish moss. After each addition of mass, the displacement from the original point was measured, until the plant broke.

C. Dielectric response

With a zero field and a magnetic field, the capacitance of the Spanish moss was tested. A small segment of a Spanish moss sample was put onto a plate using silver paste. Another strip of silver paste was spread across the top, without the two layers of paste contacting each other. The plate containing the sample was placed in the bottom of a probe. A coaxial cable in the probe has gold wire that is attached to the Spanish moss. A small heater is connected to the bottom of the probe to regulate temperature, and this open section containing the heater and sample are securely wrapped for the experiment. Air in the probe is pumped out, so water in the air does not affect the results, and freeze when liquid nitrogen is used. The capacitance was measured at room temperature with an HP 4275A multi frequency LCR meter, and the probe is then placed in a small bucket. Frequency is set at 10 kilohertz, liquid nitrogen is poured into the bucket, and the moss is allowed to cool and freeze. Temperature is monitored with a Conductus LTC-20 temperature controller. When the sample reaches its lowest temperature and has a steady reading, it is brought back up to 300K. The frequency is changed to 100 kilohertz, and the experiment is repeated. This is done again for a frequency of 200 and 400 kilohertz. With the same sample, the probe was inserted into a magnet, and capacitance was measured with a magnetic field from zero to 4.8 tesla. After completing this run, a magnetic field was used again, going from zero to 3 tesla, and a final measurement with zero field.

The zero field capacitance test was done again, but only using 10 kilohertz frequency. Initial setup was performed in the same manner, the air in the probe was pumped out, and the capacitance was measured at room temperature. As before, the end of the probe containing the sample was placed in a small bucket of liquid nitrogen. The capacitance was measured as the sample cooled and then was brought back up to room temperature. Once at room temperature the sample was left in the probe, and capacitance was recorded over a period of days. The sample could slowly die off, while there was no air in the probe. Once the capacitance became stable, the probe was pumped out again since there is a chance for leakage, and water in the sample would have evaporated. After pumping, capacitance was measured and the sample was placed in liquid nitrogen to cool, and then brought up to room temperature.

Several tests were also performed, applying magnetic fields and looking for magnetization in the moss. These tests include the EPR, NMR, SQUID, and PPMS.

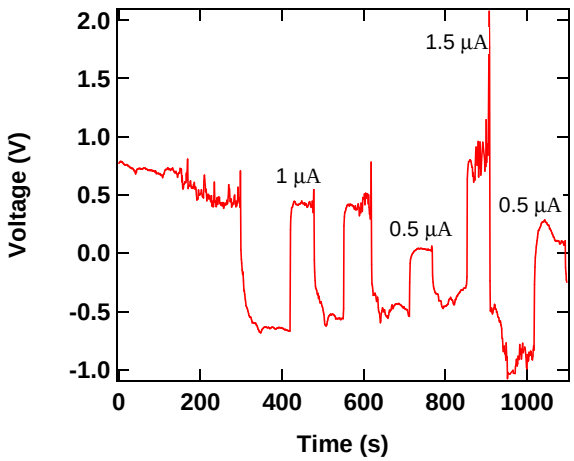

FIG. 5: Resistance of Spanish moss when salt water is applied. The current was changed to check the obedience of Ohm's law.

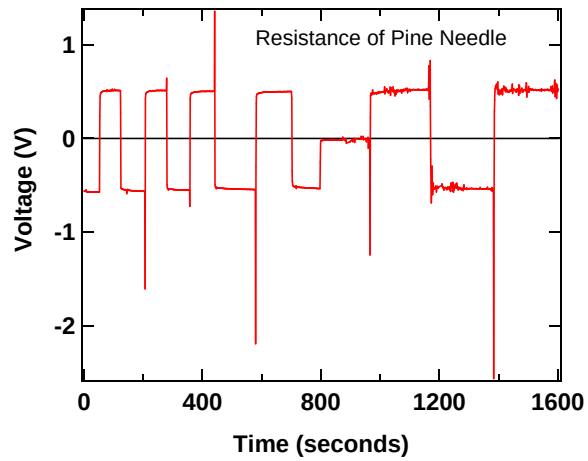

FIG. 7: Resistance of pine needle when Pedot is applied.

III. RESULT

The resistance test using salt water (FIG. 5) shows a steady voltage even when current is changed, but the results using Pedot (FIG. 6) show the voltage continues to rise with time. Taking data from the early part of the Pedot test may be best, since the plant could absorb the polymer, making it more conductive. The resistance of the pine needle (FIG. 7) was constant, which may be due to the surface of the plant being more dense than the Spanish moss. This less porous surface doesn't allow electricity to flow as easily through the plant. Before current changes there is a jump in the data, most likely from the sensitivity of the equipment.

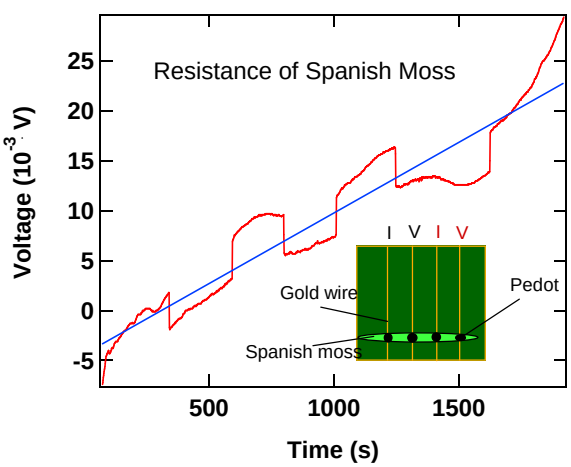

FIG. 6: Resistance of Spanish moss when Pedot is applied with I=10nA. The resistance is time dependent, and the sudden changes in voltage are due to polarity of the current being changed.

The elasticity test revealed that Spanish moss could hold 80 grams or more before breaking. The moss will continue to stretch, at least 8 micrometers, until breaking as shown in Fig. 8. Young's modulus can be calculated

$$\sigma = E\xi, \tag{1}$$

where σ is stress, E is elasticity, and ξ is strain. These results are given in table I. The first test of capacitance

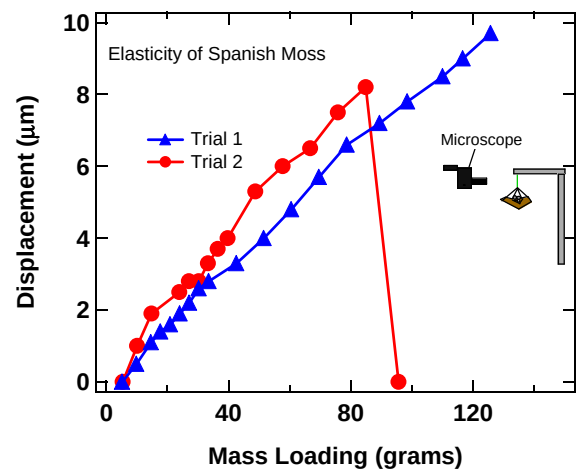

FIG. 8: Elasticity of Spanish moss, displacement versus the mass loading. The blue line is trial one, the moss did not break, and the red line is trial two, showing the moss broke with the addition of 10.711 grams and a final displacement of 8.2 micrometers.

show each result to frequency changes. Transition points were similar for temperature decrease and temperature increase; however, the results for the transition point in temperature increase are more accurate since the change in temperature is slower and more controlled. FIG. 9 (bottom) shows the imaginary portion, which was used to deduce the results in FIG. 10 and table II. From FIG. 11, it is hard to determine what effect the magnetic field has on the plant. As the sample dies, the capacitance decreases, resulting in a higher transition point in temperature. It is difficult to say that the higher transition is due to the magnetic field or the sample drying out.

TABLE I: Table of Resistance and Elasticity tests. Different samples were used for each, as indicated in column one.
(S. M. = Spanish Moss and P. N. = Pine Needle)

Sample	Resistance MΩ	Resistivity $\Omega.m$	Elasticity $GN.m$
S. M. 1	0.5	4.79	-
S. M. 2	2.7	17.7	-
P. N.	0.0357	0.78	-
S. M. 3	-	-	58.6
S. M. 4	-	-	80.8

The results of the EPR in FIG. 12 show manganese is present with the six peaks between 3100 and 3600 Gauss. There is also a strong peak appearing around 145K, which could be from the presence of iron III.

DC and AC measurements were taken with the PPMS. With the DC measurement, the sample is magnetized by a constant magnetic field and the magnetic moment of the sample is measured. This produces the DC magnetization curve M(H) (FIG. 14) The AC measurement has two parts: in phase, or real part (χ') and out of phase, or imaginary part (χ''). The real part (Fig. 13 Top) is the slope of the DC magnetization curve M(H), and the imaginary part (Fig. 13 Bottom) indicates the dissipative processes. The dissipation is due to eddy currents.

In the PPMS data for Spanish moss, there is increasing magnetization as the temperature decreases in the DC and AC in-phase data. The SQUID results in FIG. 15 are inconclusive. The lowest attainable temperature for the equipment is 2.0 K, and our results show no magnetic ordering.

TABLE II: Data taken for FIG. 10

f (kHz)	T (K)	ln(f)	$T^{-1}(K^{-1})$
10	247	2.3	0.00405
100	256	4.6	0.00391
200	267	5.3	0.00370
400	285	6.0	0.00351

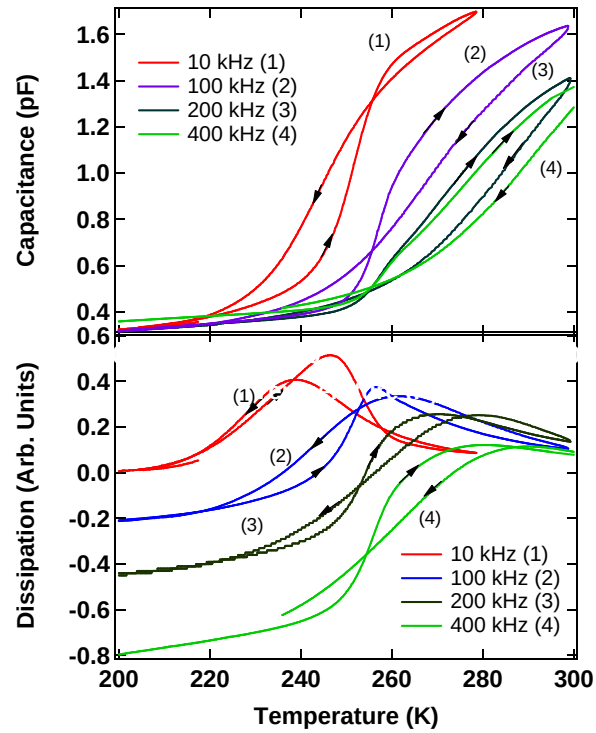

FIG. 9: Capacitance (Top) and Dissipation (Bottom) versus temperature, arrows indicate direction of temperature change. Transition is the peak of the temperature increase.

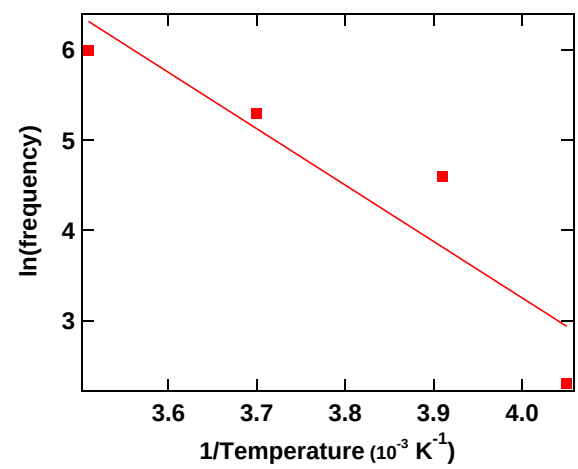

FIG. 10: The slope of ln(frequency) over 1/Temperature

IV. DISCUSSION

Each test of resistance gave different results, but the calculated resistivity is relatively similar. Using salt water to test resistance seemed to yield an accurate calculation of resistivity. Although this method appeared to work well, the water continued to evaporate, making it difficult to keep a constant reading. Application of additional salt water caused severe spikes in the data. Using Pedot was another method that allowed for accurate calculations of resistivity. A constant reading was not as easy to attain as it was using salt water. As shown in FIG. 6, resistance seems to be time dependent. This result may be due to the plant drying out, as the data will change when water is lost. The following equation was used to find resistance from the Pedot test, where R, I, t, and c are resistance, current, time, and a constant, respectively.

$$R = \frac{slope \times t}{I} + c. \tag{2}$$

Resistivity could be calculated in the same way it was found in the salt water resistance test, by using

$$\rho = \frac{R\pi r^2}{l}. \tag{3}$$

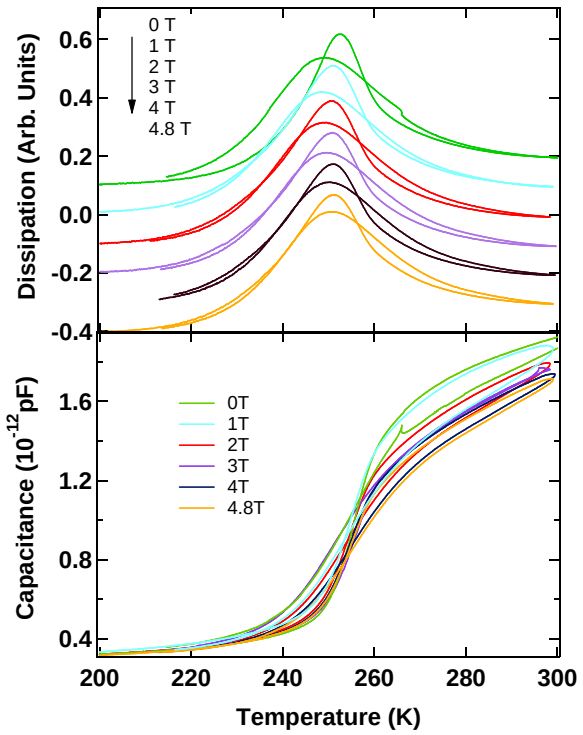

FIG. 11: Capacitance with the influence of a magnetic field. Top: shows the imaginary portion, the graph is vertically offset to see peaks in dissipation. Bottom: shows Capacitance of different strengths in magnetic field.

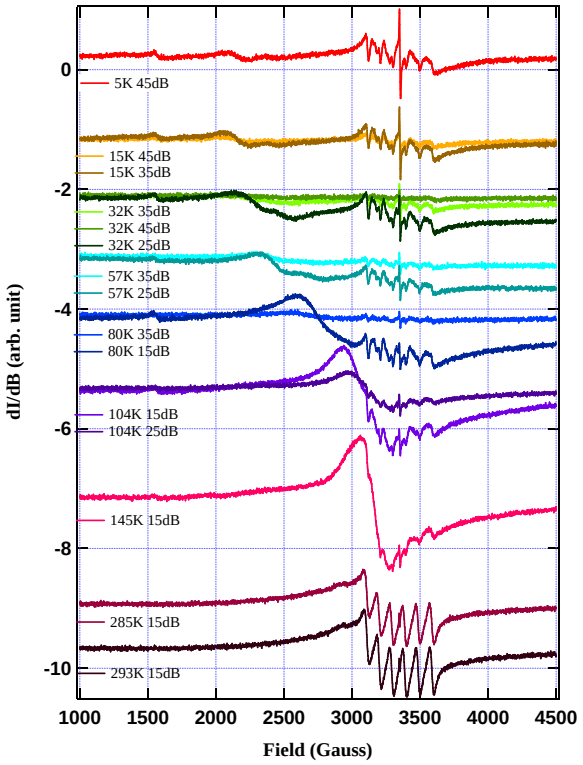

FIG. 12: EPR results on Spanish moss. The six peaks show manganese is present, and the large spike especially noticeable at 145K is possibly iron III

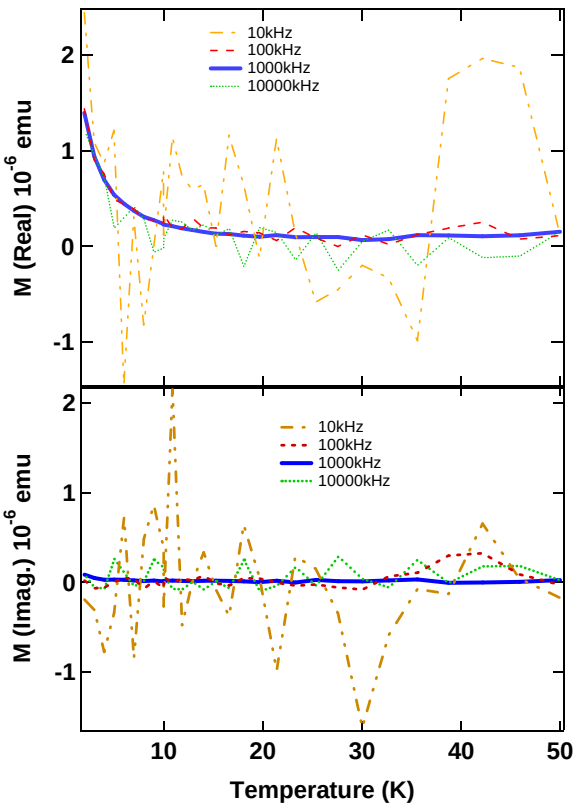

FIG. 13: PPMS AC magnetization. Top: in-phase, Bottom: out-of-phase

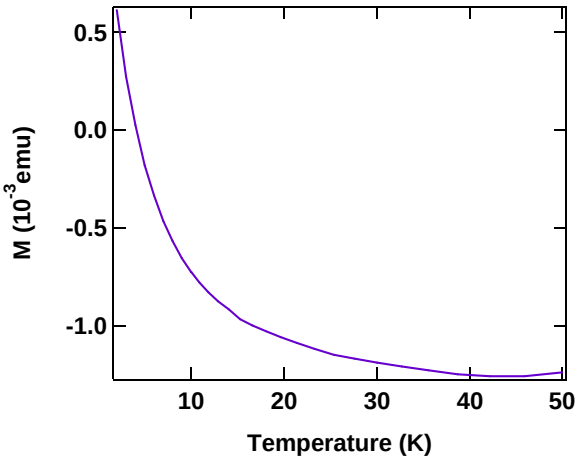

FIG. 14: PPMS DC magnetization.

In this equation, r is the radius of the piece of Spanish moss, and l is the length of the contacts between voltage points. The Pedot method was also used with a pine needle simply to compare the results of Spanish moss to another biological sample.

Measuring capacitance, when the moss had dried out was not very successful. In all but one case, no transition during temperature change occurred. In the case a transition did occur, two peaks were formed in the dissi-

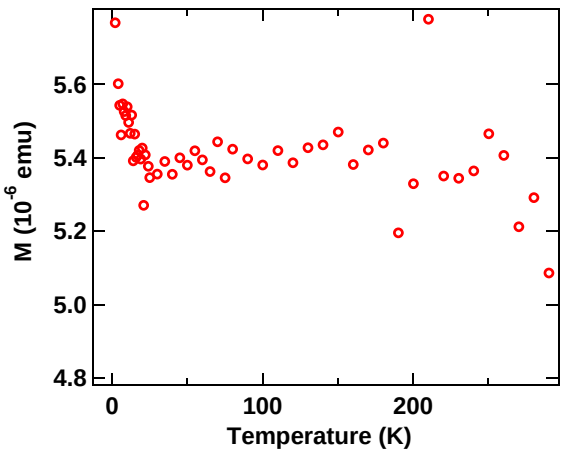

FIG. 15: SQUID magnetization.

pation, but since then, the results have not been reproduced. The following equation was used to calculate the dielectric constant K, where C, ϵ_0, A, d are capacitance, permitivity of vacuum, area of silver paste, and diameter.

$$C = \frac{K\epsilon_0 A}{d}. \tag{4}$$

In the case of Spanish moss, the dielectric constant was found to be 75.5, not surprisingly very close to water, which has a dielectric constant of around 80.

V. CONCLUSION

These results show some of the physical properties of Spanish moss, but there is still more research to be done before Spanish moss could be used to produce energy for anything other than itself. Since chlorophyll is used by plants to give them energy, we should figure out the chlorophyll content of Spanish moss, and then determine the best way to process it for our own use. We need to learn more about the biological properties of Spanish moss, and what effect they have on the physical ones.

Acknowledgments

I would like to thank Professors J. S. Brooks, N. Dalal and Brooks' group: E. Jobiliong, R. Vasic, T. Tokumoto, and L. Lumata for all of their help and patience, as well as the Center for Integrated Research and Learning for this opportunity. This research was supported by NSF 0203532, the National Science Foundation's Research Experience for Undergraduates, and the National High Magnetic Field Laboratory.

[1] Wikipedia: The Free Encyclopedia (2005), URL `http://www.en.wikipedia.org/wiki/tillandsia`.

[2] N. P. Arny, *Spanish Moss and Ball Moss* (2005), URL `http://www.sfrc.ufl.edu/Extension/scfor52.htm`.

[3] W. Knight, *Most efficient solar cell yet revealed* (2003), URL `http://www.newscientist.com/article.ns?id=dn4033`.