Observation of X-ray Emissions Resulting From Scotch Tape: Final Report

Society of Physics Students at Illinois Institute of Technology

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Abstract

It has been shown that if ordinary scotch tape is unrolled in a vacuum, it will emit x-rays and visible light. The proposed experiment will investigate this property by building a suitable vacuum chamber and observing the x-rays from various tapes, unrolled at different speeds, and under different vacuum conditions.

Introduction

It has been known since 1953 [1] that scotch tape can emit x-rays when being unrolled in a vacuum. However, it was not fully investigated until recently, when Camara et. al. studied the resulting spectra of both x-rays and visible light emitted [2]. They proposed the following physical mechanism: As the tape unrolls, the sheet of tape and the rest of the roll build up an electric field by separating charges. Eventually the electric field becomes large enough to trigger a discharge, which accelerates electrons until they hit the bulk roll of tape. The electrons then decelerate, emitting bremsstrahlung x-rays. This hypothesis is supported by the x-ray spectrum they obtained, which is shown in Figure 1 and appears to be a typical bremsstrahlung distribution.

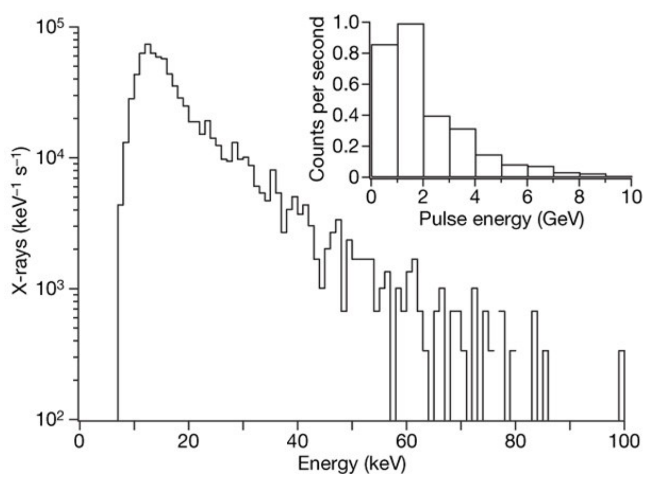

Figure 1: X-ray spectrum observed by Camara et. al. Peel speed was about 3.3 cm/sec, with pressure at 1 mTorr.

Methods

The methods used in this experiment were very similar to that done by Camara et. al. An electric motor spins a drive shaft, which connects to a rotary feedthrough and works to spin a cylinder within the vacuum chamber. The original design for this set-up uses a 1.4 amp step-motor. However, we realized in trial runs that a simple electrical drill will run the tape fast enough to emit x-rays. A second, stationary cylinder holds the roll of tape. The rotating cylinder will be used to unroll the tape at a speed controlled by the motor. The vacuum chamber is a tubular design made of stainless steel with eight portholes evenly spaced around the outside surface and a removable top made of 1 inch thick glass. A spectroscope is planned to be used to characterize the visible light emitted by the tape, as well as an x-ray detector that will characterize the x-rays emitted.

Work through June 2010

First, we found a suitable vacuum pump that we can use. After spending over a month attempting to repair a leaky diffusion pump, we switched gears and began to use a working mechanical/diffusion pump owned by the Physics department and used for classroom laboratory settings.

We also found a vacuum chamber which we can use, shown in Figure 2. Since this chamber was used previously by another group, we had to dismantle the parts. The top section is glass, which makes it very easy to see what is going on. As Figure 2 shows, there is an electrical feedthrough already attached. We have not removed this, unsure if we will find a way to use it. There is also a gas inlet; this will be removed once all of the aluminum plates are finished.

Figure 2: The vacuum chamber we will use

One of the ports will be used by the rotary feedthrough shown in Figure 3. This will mount on a base plate and be connected to a motor on the outside of the vacuum chamber. It is easy to replace the o-rings if they fail in use, which might happen during the higher rpm trials.

Figure 3: Rotary feedthrough we will be using

We also designed the x-ray detection scheme. The tape will be placed in a mount on the inside of the vacuum chamber. The mount will be positioned slightly lower than the feedthrough, so the tape will unroll approximately horizontally from the top. A scintillator tube will be placed directly above the glass to measure the energy spectrum of the x-rays.

Work through December 2010

Due to conflicts with the availability of the much useful diffusion/mechanical pump system, we were forced to switch vacuum systems again. We settled on an old diffusion pump system in which we replaced the diffusion pump with a mechanical pump and sealed all unnecessary openings. All extra aluminum plates were finished and both the electrical and gas inlets were removed and covered as to ensure a tight seal for the system. An inlet that coupled the rotary feedthrough to the motor was also constructed, as well as a shaft to hold the unraveling tape in place. Both designs proved to be challenging in efficiency of unraveling the tape, unraveling it in a vacuum setting, and unraveling it in such a way that x-ray detection and spectroscopy can be done simply.

When all pieces and parts were created for the system, we did a multi-step cleaning process to provide the best environment for a low vacuum setting. The lowest we have gotten this system to is 120 mTorr, but we can consistently reach the 130-150 mTorr range. These measurements were done with our newly purchased vacuum gauge. Dry runs show us that the fixtures that hold the tape are only steady for the Scotch tape brand. Other brands that use different adhesive cause the rod holding the tape to get much closer to the rotating feature than originally planned and inhibiting any measurements.

Upon attempting to obtain measurable results, we learned that the 1 inch glass top is too thick to allow for consistency in x-ray spectral analysis. Instead, we placed fluorescence paper inside the vacuum, below the x-ray emission region, and attempted to see the presence of x-rays. This was successful! These viewings can be seen on the YouTube video we created: http://www.youtube.com/watch?v=7vRHnZfeiF8.

Future Work

We were planning to order a new speed-controlling stepper motor system that would allow us to do various experiments of x-ray emission at various speeds, which would replace the simple electrical drill we are currently using. However, budgetary restrictions do not allow us to purchase the motor we originally wanted. We are currently going through all available motors in the department and weighing the possibility of their use. The group will continue working on this project into the spring, finding a suitable replacement for the thick glass plate so that easier and more reliable results of x-ray emission can be generated from outside of the vacuum system. Once this is done, the group can move forward with original experimentation plans: mapping out differences among different brands and different speeds of scotch tape inside a vacuum system.

Expectations

It is expected that varying the speed will effect the intensity of radiation, but not the energy. This is due to the hypothesized mechanism described above. A faster speed will mean charge will build up more quickly, and discharges will occur with higher frequency. This higher frequency will result in a higher observed intensity per unit time. However, there is little to suggest that a different amount of energy will be released in each discharge.

The brand of tape will likely be irrelevant to the observed spectrum of visible and x-ray radiation. This is because any chemical differences there are between the brands should be irrelevant to the x-ray spectrum. The Van Der Waals forces, largely responsible [3] for tape sticking to a surface, are much too weak to explain x-ray emission. Small changes in chemistry would alter the Van Der Waals strengths slightly, but probably not the x-ray emissions which are governed by other processes.

Budget

Summary of Expenditures

McMaster Carr	Raw materials, tooling, o-rings, fasteners	304.20
Kurt Lesker, Inc.	Rotary feedthrough & Vacuum gauge controller & gauge	617.37
Machine Shop	Machining costs – BCPS Shop	200.00
Total		1121.57
SPS Project Fund		1090.00
Physics Department Funds		31.57

References

[1]: Karasev, V. V., Krotova, N. A. & Deryagin, B. W. Study of electronic emission during the stripping of a layer of high polymer from glass in a vacuum. [in Russian] *Dokl*. Akad. Nauk. SSR 88, 777–780 (1953)

[2]: Camara C. G., Escobar J. V., Hird J. R., & Putterman S. J. Correlation between nanosecond X-ray flashes and stick-slip friction in peeling tape. Nature 455, 1089-1092 (2008)

[3]: Gay, C. & Leibler, L. Theory of tackiness. Phys. Rev. Lett. 82, 936–939 (1999)