NEWSLETTER

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String Theory—A Unified Theory of Forces, Matter and Spacetime

By Geoff Potvin

String theory is a field that has had a significant impact on the physics community even though it is only 30 years old. It is designed as a unified field theory, and its main postulate is that all the known fundamental "particles" are tiny loops of a one-dimensional string. All particles are made of the same kind of string: different vibrational modes and energetics behave like different particles, and the strings can be closed (like an elastic band) or open (having two endpoints). This description of objects as strings is very powerful: extreme gravitational objects like black holes also have a stringy, fully-quantum description which gives researchers the ability to count the entropy of certain gravitational systems and resolve the spacetime singularities for some black holes. It also gives the hope of studying what happens when black holes evaporate, and finding a solution to the black hole information problem—the apparent loss of coherent information, other than mass, charge and angular momentum, when matter falls into a black hole of General Relativity.

An important component to modern string theories is the necessity for spacetime "supersymmetry". Supersymmetry describes a sort of pairing between the usual matter in the Universe (fermions) and the force-carriers (bosons), and involves mixing up our concepts of spacetime coordinates and particle descriptions. Though it is clear that there is no unbroken supersymmetry at the energies we have probed (we would see at least twice as many particles in the Standard Model!), most researchers in the field expect that there must be supersymmetry in the correct unified field theory and that the supersymmetry breaks at energies just beyond the current capability of particle accelerators. So it is expected that in the next generation of particle accelerators, supersymmetric particles will be detected. This is not a necessary and sufficient condition for the existence of a string theory description of the Universe, but will lend a great deal of support to this way of looking at high energy physics.

A well known prediction is that a consistent, supersymmetric string theory lives in ten dimensions. Since we seem to live in only four dimensions, much effort is spent working on compacting six of the dimensions in various models. This leads to a plethora of phenomenological predictions and various cosmological models. It turns out that there are other objects that exist in string theory, notably D-branes. D-branes are dynamical objects analogous to higher dimensional membranes, and can be thought of as surfaces upon which the endpoints of all open strings must lie. One of the popular alternatives to full compaction is that the Universe is five dimensional (four space, one time), with the physics of the Standard Model existing only on a three dimensional brane and evolving with time, with gravity interacting in all five dimensions.

The difficult aspect of testing the predictions of a unified field theory is that it seems quite unlikely that it will be possible to build accelerators big enough to generate the required energies. Gravity, for example, is expected to become very "quantum" only near the Planck energy, which corresponds to probing at a distance of 10^{-33}cm! So string theorists have also turned their attention to astrophysical data, especially the cosmic microwave background radiation (CMBR), and studies of the relation of string theory to cosmology. The CMBR is the "echo" of the Big Bang that was emitted when the young expanding Universe had just become transparent to light. The small variations in temperature of the CMBR can tell us important information about the level of quantum fluctuations in the very early Universe. Furthermore, recent data supports the idea that our Universe is in a period of exponential expansion driven by some sort of dark energy, which makes up nearly 70% of the total mass-energy of the Universe. This was an unexpected finding, and researchers are working hard to understand how such a Universe could arise from string theory.

In the Department of Physics at the University of Toronto, the group of researchers (consisting of faculty members, post-doctoral fellows and graduate students) who are studying physics beyond the Standard Model, including string theory and closely related topics, is currently around a dozen people. Geoff Potvin is a Ph.D. Candidate in the Department. His research focuses on the resolution of spacetime singularities in string theory.

The Demonstration Corner
A Simple Demonstration of the Photoelectric Effect
By Eknath V. Marathé, St. Catharines, Ontario

INTRODUCTION

Following the work of Gustav Kirchhoff, James Maxwell, Heinrich Hertz, Wilhelm Hallwachs, Philipp Lenard, John Rayleigh, and James Jeans, Wilhelm Wien worked at finding out the distribution of energy radiated by a black body. Wien's energy radiation equation for a black body failed to agree with the observed values in the low frequencies (long wavelengths) region of the blackbody energy radiation spectrum (Wien's displacement law). Also, the Rayleigh-Jeans energy radiation equation for a black body failed to agree with the observed values in the high frequencies (short wavelengths) region. This failure is known as the ultraviolet catastrophe.

In 1900, Max Planck worked out a relatively simple energy radiation equation for a black body that described the distribution of radiation accurately over the entire range of frequencies. His equation was based on a crucial assumption: radiant energy is not infinitely sub-divisible. Like matter, it exists in "particles." These particles Planck called quanta, or in the singular, "quantum." He further suggested that the size of the quantum, also known as "photon," for any particular form of electromagnetic radiation, was in direct proportion to its frequency. In the visible spectrum, a photon of violet light would therefore contain more energy than a photon of red light. The small constant that is the ratio of the energy of a photon (E) and the frequency(ν) of the photon radiation is called Planck's constant and it is symbolized as h ($h = E/\nu$). It is now recognized as one of the fundamental constants of the universe. Planck's theory, known as Quantum Theory, was applied by Einstein in explaining the photoelectric effect.

DEMONSTRATION

Remove the knob of a gold-leaf electroscope and attach a zinc plate about 10 cm × 10 cm in dimensions[1]. The sharp corners of the plate should be turned into a circular arc to eliminate the possibility of leaking the charge through sharp points. The electroscope will function properly in whatever weather, if polystyrene insulation is used. A source of ultraviolet light, such as a quartz mercury lamp, or carbon arc, or a spark discharge between zinc or aluminum electrodes, or PSSC course ultraviolet light source, is arranged to illuminate the zinc plate[2]. The zinc plate must be cleaned by sandpaper (never by emery paper) immediately before using for the demonstration, so as to remove the oxide layer that forms on the surface of the plate because of exposure to the air[1].

Charge the electroscope positively. There should be no appreciable difference in the natural rate of leak determined both with and without illuminating the zinc plate by white light[3]. The plate is then charged with negative charge. Illuminate the plate with ultraviolet light; the leaf of the electroscope falls. This happens because electrons are ejected from the plate under the action of the ultraviolet light. Charge the plate again with negative charge. A glass plate is held a short distance from the source of ultraviolet light and the light is directed through the glass towards the plate; the deflection of the gold leaf does not change. This confirms that photons of the ultraviolet light were responsible for ejecting electrons from the zinc plate.

Other materials, such as aluminum or brass, may be used, but the effect is much smaller; all clean metals will show the photoelectric effect, to some extent, with ultraviolet light.

DISCUSSION

Einstein maintained that a minimum frequency of light (the threshold frequency), which corresponds to a minimum photon energy, is required to force an electron out of a given metal. Brighter light (more photons) would bring about the emission of more electrons. Light of higher frequency, however, would have more energetic photons and would bring about emission of more energetic electrons. Light that has a lower frequency than the threshold frequency would be made of photons with such little energy as to bring about no electron emission at all. The energy content of such low-frequency photons would be insufficient to break an electron away from the metal. Of course, the threshold frequency would be different for different metals.

When the plate is charged positively and then illuminated by ultraviolet light, a few electrons may be ejected but the plate's attractive field pulls them back in[4]. On the other hand, if the plate is charged negatively and then illuminated with ultraviolet light, the leaf falls, and if the illumination is continued for a short time after that, one may see the leaf diverging again. Removing the light source and then testing the type of charge on the plate in a usual manner, one would find that the charge is positive. This is because, after a large number of electrons have been ejected from the zinc plate, the plate has a net positive charge for a short while, sufficient enough to be shown by the deflection of the gold leaf. This charge is then slowly neutralized by the natural absorption of electrons from the surrounding air.

If one of the glass faces of the electroscope is marked with angular calibration (projection electroscope), one can project the deflection of the leaf on a screen.

The photoelectric effect obeys the Einstein photoelectric equation:

$h\nu$	=	W	+	$\frac{1}{2}mv^2$
Energy of the incident photon.		Minimum energy required to remove an electron from its atom (threshold energy, or work function)		Maximum kinetic energy of the ejected electron.

Some electrons in a given metal will be more tightly bound to the metal than will others. These electrons will require more energy than the minimum to release them from the metal. Thus, for photons of a given frequency, ν, there is a range of kinetic energies that the released electrons will have, with the maximum kinetic energy corresponding to electrons that were loosely bound and were ejected with only the minimum energy (W) being required.

REFERENCES

[1] Harry F. Meiners, Ed., *Physics Demonstration Experiments* (AAPT and The Ronald Press Co., New York, 1970, Vol. 2) p.1169.

[2] Wallace A. Hilton, *Physics Demonstration Experiments* (AAPT 1971), Revised Ed. P.91.

[3] Richard Manliffe Sutton, Ed., *Demonstration Experiments in Physics* (McGraw-Hill Book Company, Inc. New York, 1938), pp.488-489.

[4] Eric M. Rogers, *Physics for the Inquiring Mind* (Princeton University Press, 1960) p.724.

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Submissions describing demonstrations will be gladly received by the column editor

Who Said Air Resistance Was a Drag?

By Paul Passafiume

The concept of air resistance, while fun for teachers, can be perhaps a little dry and somewhat confusing for our students. The topic, though rich, is usually covered briefly and often using Socratic methods, which may leave our students in an unenthused haze. Myself, and a clever math teacher at our school, thought of a way to bring clarity and enjoyment to the subject. Here's what you'll need:

- A computer, motion sensor, interface box, and DataStudio software (or equivalent)
- Some string (I used butcher twine), a large diameter plastic straw, a Styrofoam dinner – sized plate
- A couple quarters (kids will have these!)

Poke a hole through the centre of the plate, and feed the straw through it until the plate is at the centre of the straw. Using duct tape, secure the plate to the straw. Cut enough string from the roll to reach from the floor to nearly the ceiling (should be about 3 m, or so). Feed the string through the straw and lift the plate up to the ceiling. The student holding the plate should also hold the motion sensor above it so the sensor can 'see' the plate as it falls. This can be done easily by pressing the string to the front of the sensor with one hand, and holding the plate with the other. When ready, drop the plate and begin collecting data. You'll want to send the data to a velocity – time graph. When that trial is complete, repeat the activity two more times by taping one quarter, and then a second to the centre of the plate. I had three stations up so that all the students could be involved.

The results obtained are really quite amazing. Each trial has a very well defined period of acceleration, which gradually tapers off as the plate reaches terminal velocity. It is clearly seen that the more massive plates have a longer period of acceleration, and therefore reach a larger terminal velocity. Also, the more massive the plate the steeper the velocity – time curve (now why would that be?!).

I tried this activity for the first time with my 4U class, and it was a real success. This kids absolutely loved it, and discussion it generated was just amazing. Having completed the exercise, I was sure that they both understood the material and had fun doing it! And who said air resistance was a drag? ☺

Let's Play: Quotable Quotes!

Here's the deal. Identify the famous scientist who said the quote below. Be the first person to email your response (c/w mailing address) to the editor, Paul Passafiume, at paulpassafiume@hotmail.com and you'll win a prize! It's that easy. Here we go!

"It's a true miracle that modern education hasn't yet completey smothered the curiosity necessary for scientific study. For without the required encouragement, and especially freedom, this fragile plant will wither. It is a grave mistake to believe that the pleasures of observation and inquiry can be induced by constraint and a sense of duty."

Quote sumitted by Miss. Connie Chang, Markville Secondary School.

Attention ALL teachers: The next OAPT conference will be held May 22 – 24, and hosted by the University of Western Ontario. The theme of this year's conference is 'medical physics'. With FREE workshop presentations covering grade 9 electricity, grade 10 motion, and using computers in the classroom the conference is sure to be of interest to all. Workshops begin Thursday evening, from 7 – 9, after the BBQ.

Do you want to give back to your profession? Participate in the OAPT!

This wonderful organization needs volunteer help in the following capacities:

- Guest presenters
- Conference organizers, and facilitators
- Members of the executive committee
- Article, and classroom idea contributors for the Newsletter

New articles, ideas, or other information items may be sent to Glen Wagner (glenn.wagner@ugdsb.on.ca) or Paul Passafiume (paulpassafiume@hotmail.com). Ideas for demos may be sent to Ernie McFarland (elm@physics.uoguelph.ca).

Membership Matters!

Join the Ontario Association of Physics Teachers! Members receive a Newsletter and reduced registration rates at the annual conference.

As well, from time to time, the Association makes available special resources. Examples have included reprints of **"Demonstration Corner"** articles from the **Newsletter**, and the videotape, **"The Physics of Dance,"** from a presentation at one of the annual conferences.

To become a member of the OAPT, send a cheque for $8 (or a multiple thereof) payable to OAPT to:

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Attention physics teachers: Arizona State University in Tempe is offering summer graduate courses in physic pedagogy, interdisciplinary science, and contemporary physics. These courses may be suitable for Ontario's PLP program (verification required). Courses are offered mainly in July, 2003. More information is available from Jane.Jackson@asu.edu, 480.965.8438, or from http://modeling.asu.edu.