Sustainable Evil

- Midway through the semester, I became curious about other forms of energy we had yet to discuss in class.
- I started wondering about the differences and commonalities between static and current electricity, and if it were physically possible to convert one to the other.
- I didn't really know what static electricity was. In fact, I still don't fully understand it.
- Then again, it seems that static electricity is generally not well understood, which is surprising given how long we've known about it.

- Static occurs when a material that does not conduct electricity becomes imbalanced in the number of electrons and protons at its surface.

- Owing to the way their molecules are constructed, certain materials have a tendency to gain or lose electrons through physical contact with dissimilar materials – essentially electrons are passed from one material to another by rubbing, which, when they are moved apart, creates a voltage difference between them. This is called the “triboelectric effect”.

- We have long known which materials tend to lose electrons and which ones tend to gain them. They are listed in a type of table called a triboelectric series.

Col.4: Notes:

Polyurethane foam	+60	+N	All materials are good insulators (>1000 T ohm cm) unless noted.
Sorbothane	+58	-W	Slightly conductive. (120 G ohm cm).
Box sealing tape (BOPP)	+55	+W	Non-sticky side. Becomes more negative if sanded down to the BOPP film.
Hair, oily skin	+45	+N	Skin is conductive. Cannot be charged by metal rubbing.
Solid polyurethane, filled	+40	+N	Slightly conductive. (8 T ohm cm).
Magnesium fluoride (MgF2)	+35	+N	Anti-reflective optical coating.
Nylon, dry skin	+30	+N	Skin is conductive. Cannot be charged by metal rubbing.
Machine oil	+29	+N	
Nylatron (nylon filled with MoS_2)	+28	+N	
Glass (soda)	+25	+N	Slightly conductive. (Depends on humidity).
Paper (uncoated copy)	+10	-W	Most papers & cardboard have similar affinity. Slightly conductive.
Wood (pine)	+7	-W	
GE brand Silicone II (hardens in air)	+6	+N	More positive than the other silicone chemistry (see below).
Cotton	+5	+N	Slightly conductive. (Depends on humidity).
Nitrile rubber	+3	-W	
Wool	0	-W	
Polycarbonate	-5	-W	
ABS	-5	-N	
Acrylic (polymethyl methacrylate) and adhesive side of clear carton-sealing and office tape	-10	-N	Several clear tape adhesives are have an affinity almost identical to acrylic, even though various compositions are listed.
Epoxy (circuit board)	-32	-N	
Styrene-butadiene rubber (SBR, Buna S)	-35	-N	Sometimes inaccurately called "neoprene" (see below).
Solvent-based spray paints	-38	-N	May vary.
PET (mylar) cloth	-40	-W	
PET (mylar) solid	-40	+W	
EVA rubber for gaskets, filled	-55	-N	Slightly conductive. (10 T ohm cm). Filled rubber will usually conduct.
Gum rubber	-60	-N	Barely conductive. (500 T ohm cm).
Hot melt glue	-62	-N	
Polystyrene	-70	-N	
Polyimide	-70	-N	
Silicones (air harden & thermoset, but *not* GE)	-72	-N	
Vinyl: flexible (clear tubing)	-75	-N	
Carton-sealing tape (BOPP), sanded down	-85	-N	Raw surface is very + (see above), but close to PP when sanded.
Olefins (alkenes): LDPE, HDPE, PP	-90	-N	UHMWPE is below. Against metals, PP is more neg than PE.
Cellulose nitrate	-93	-N	
Office tape backing (vinyl copolymer ?)	-95	-N	
UHMWPE	-95	-N	
Neoprene (polychloroprene, *not* SBR)	-98	-N	Slightly conductive if filled (1.5 T ohm cm).
PVC (rigid vinyl)	-100	-N	
Latex (natural) rubber	-105	-N	
Viton, filled	-117	-N	Slightly conductive. (40 T ohm cm).
Epichlorohydrin rubber, filled	-118	-N	Slightly conductive. (250 G ohm cm).
Santoprene rubber	-120	-N	
Hypalon rubber, filled	-130	-N	Slightly conductive. (30 T ohm cm).
Butyl rubber, filled	-135	-N	Conductive. (900 M ohm cm). Test was done fast.
EDPM rubber, filled	-140	-N	Slightly conductive. (40 T ohm cm).
Teflon	-190	-N	Surface is fluorine atoms-- very electronegative.

Researchers at Georgia Tech, led by professor Zhong Lin Wang, have been investigating the possibilities of using the triboelectric effect to harvest ambient energy in everyday life, through a calss of devices they have named "triboelectric nanogenerators," or TENGs.

Their research has yielded a wealth of information about how the triboelectric effect can be encouraged and maximized, as well as directed into circuitry to do useful work.

They have identified four modes of charge transfer – vertical contact-separation mode, lateral sliding mode, single-electrode mode (which can be based on either of the above physical dynamics) and freestanding triboelectric layer mode (which takes advantage of the fact that bodies moving through the environment tend to acquire static charge).

The uses they identify for this technology are both on a very small scale (self-powered sensors) and theoretically on much larger scales (un-dammed and oceanic hydroelectric, new approaches to wind power). By optimizing materials and the physical layout of the TENG, they report power densities as high as 1200 watts per square meter of surface area.

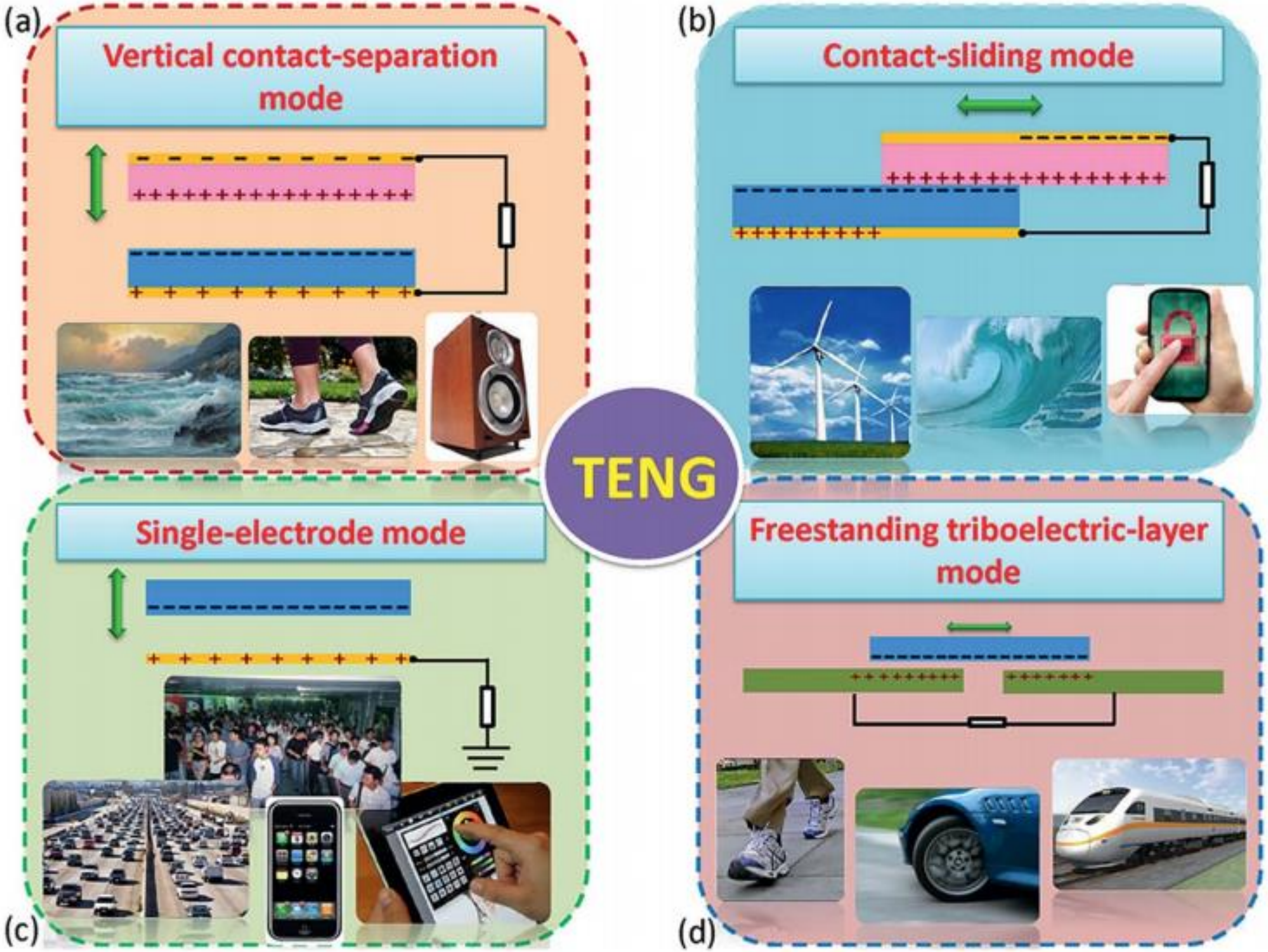


Fig. 1 The four fundamental modes of triboelectric nanogenerators: (a) vertical contact-separation mode; (b) in-plane contact-sliding mode; (c) single-electrode mode; and (d) freestanding triboelectric-layer mode.

After reading a handful of papers from these scientists, as well as a few others on the web (including researchers at Disney) I decided to take a crack at this emerging technology.

LEDs were the friendliest load I could imagine, to prove that I really was harvesting power from my system. I started to think about how to make lighting up an LED interesting, and for some wacko reason I hit on the idea of making an “evil” doll with light-up eyes. Because, y’know, why not?

My initial thought was to use hair-rubbing as a means of creating static, harkening back to elementary-school science class experiments with balloons.

I tried rubbing materials at opposite ends of the triboelectric series together and examining the outcome on a multimeter and oscilloscope. The results were not at all promising.

So I decided to try and replicate exactly the most accessible of the experiments I had read about, using the vertical contact-separation mode of TENG. In hopes of working it into the doll on which I'd become fixated, I decided that the doll's eyes would light up when he or she was squeezed.

The researchers for this experiment had assembled a generator out of one layer of copper, one layer of textured silicone film (extremely negative), compressible spacers made of polyurethane foam (extremely positive, though that wasn't listed as one of their relevant traits in the experiment) and a second layer of PET plastic (slightly negative) coated with indium tin oxide on one side (which made it conductive). I'm not certain why the researchers chose PET, given its relative place in the center of the triboelectric series, but it has been pointed out that certain materials have specific affinities for certain others, there is some debate as to how and why these relationships function in the first place, and anyway I was trying to follow the experiment in the literature as best I could.

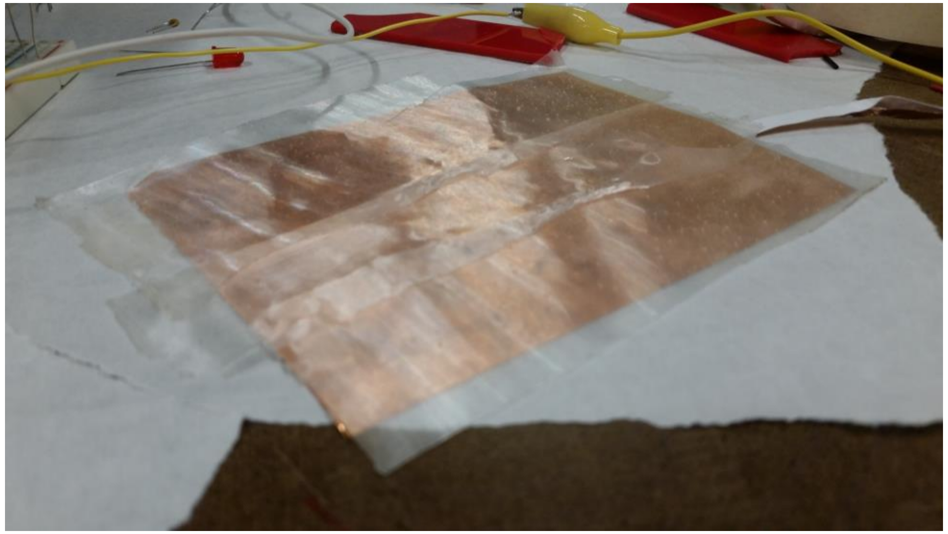
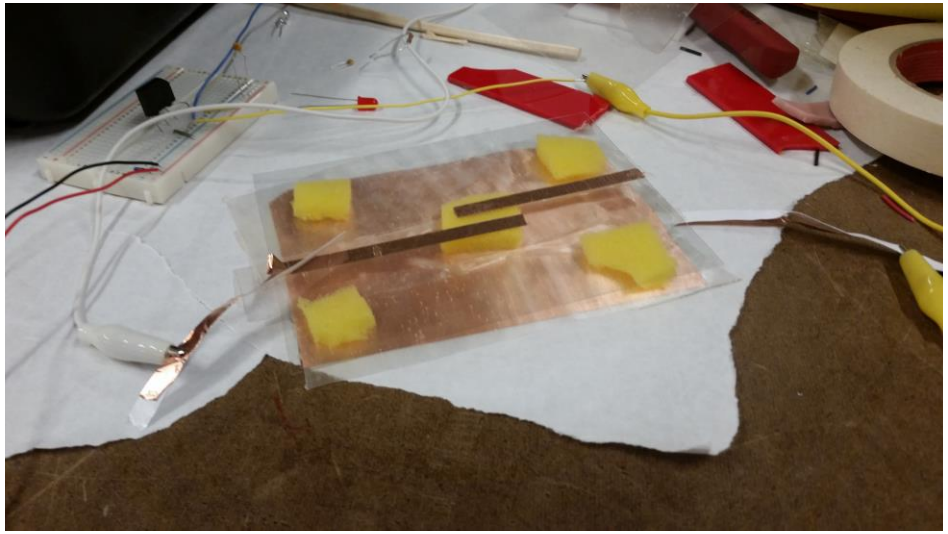
The copper I had, and, blessedly, Adafruit sells the ITO-coated PET. I bought some silicone resin and cast it between two textured placemats I bought at the 99-cent store.

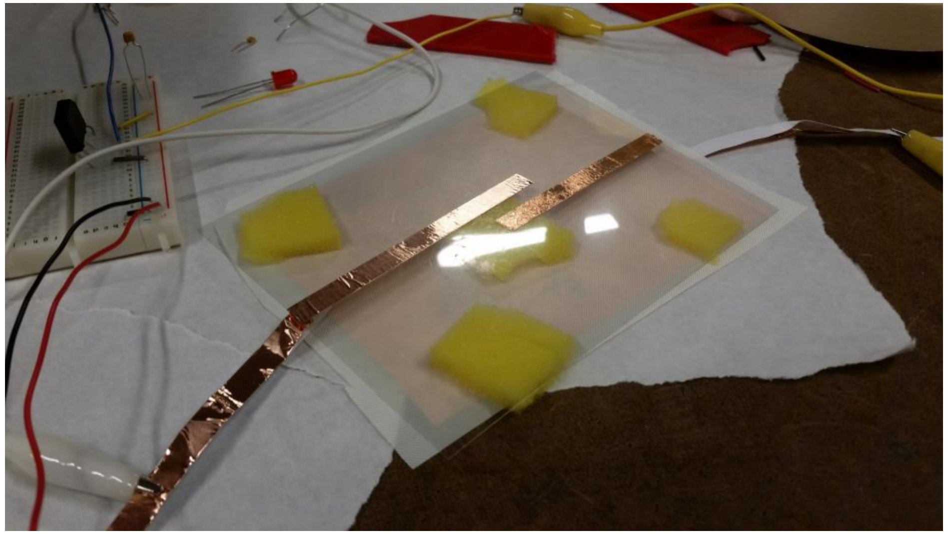
And the results were pretty interesting – by giving the TENG a good sharp whack, I easily obtained voltages above 10 V (as seen on the oscilloscope). By placing small capacitors in parallel with the TENG, I was able to smooth out the peaks a bit, and maintain an almost steady stream of around half a volt, again per the oscilloscope.

What I was not able to do was light up an LED.

Or rather, I was not able to visibly light up an LED. Placing an LED as a load across the TENG did change the readings on the scope enough that I'm fairly certain the diode was instantaneously conducting, it just wasn't conducting strongly enough, or long enough, to be visible to the human eye.

I experimented with multiple layers, different materials (replacing PET with acrylic and nylon, silicone with Teflon), different capacitor values… everything kept my numbers more or less in place, either sharp sub-microsecond spikes around a dozen volts or a smooth curve around one volt or less.



In the meantime, though, I’d become quite fond of the idea of making an evil doll. And as I realized I was probably not going to be able to use the TENG to do it, I started thinking about using more conventional means of harvesting kinetic energy to light up the eyes, and then about the most fun ways to generate that energy, and then about other things I could do with the comparatively ultra-rich power source that is a stepper motor.

And so without further ado… Li’l Beelzebub!

Li'l Beelzebub may be possessed by an unclean spirit, but he is powered exclusively by clean kinetic energy.

When you spin his head around, his bright, cheerful eyes light right up, and a cute little pentagram glows on his unholy forehead.

He even has a catchphrase!