X-Ray Flashes from Scotch Tape

Moses Marsh
Shpyrko Group
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What is going on?

- *triboluminescence*: emission of light when a material is crushed, rubbed, scratched, or pulled apart.
- Diffuse mechanical energy somehow concentrates huge charge densities over short time scales, resulting in high energy radiation during discharge.
- Has been observed in sugar and quartz crystals for centuries.
- Can also be seen as cracks form in ice cubes.
- Possibly related to lightning, “earthquake lights,” and gecko adhesion.
Experimental Setup

- Peeling force measured
- X-rays emissions detected with scintillator
- Radio emissions detected with BNC antennae
Data - Pulses

- Slips in the peeling force (black) corresponded with x-ray (blue) and radio (red) emissions
- Bottom: comparison of x-ray and radio pulses
Spectrum did not change significantly over 10 rew windings of the same roll of tape
Data – Visible Spectrum

- Black trace taken at $10^{-4}$ torr of air, gray at 1 atm.
Power

- At 1atm, it takes 50mW to peel tape at 3 cm/s.
- In vacuum, it takes an extra 3mW. Of this, at least 0.2mW goes into accelerating electrons to 30 keV, generating an average X-ray power of 2 nW. The power going into visible triboluminescence is 10 nW.
Theory

- As the tape is pulled apart, the acrylic adhesive becomes positively charged and the polyethylene roll becomes negatively charged, until the electric field becomes strong enough to trigger discharge.

- At low pressure, the discharge can accelerate electrons to high enough speed to generate Bremsstrahlung x-rays upon hitting the positive side of the tape.

- Max E-field dictated by dielectric breakdown criterion of the intermediate gas, or, in vacuum, field emission criterion.
  - Air at 1 atm breaks down at E~30kV/cm.
  - In vacuum we are talking about fields ~1000 times greater.
Theory

• Multiple models for the discharge. Using the x-ray power spectra with these models lets us estimate the number of electrons being accelerated and thus the charge densities generated.

  • Kramers limit (thick target limit of Bremsstrahlung process): describes average charge density in agreement with previous tribocharging phenomena, but doesn't account for shortness of x-ray pulses

  • Townsend discharge (avalanche gas ionization)

  • Explosive plasma emission

  • The latter two can account for the necessary spikes in charge density
X-Ray photography

- Capacitor image: tape unwound at 20 cm/s, 5 s exposure
- Finger image: tape unwound at 10 cm/s, 20 s exposure
References


