Inductors - the shocking truth

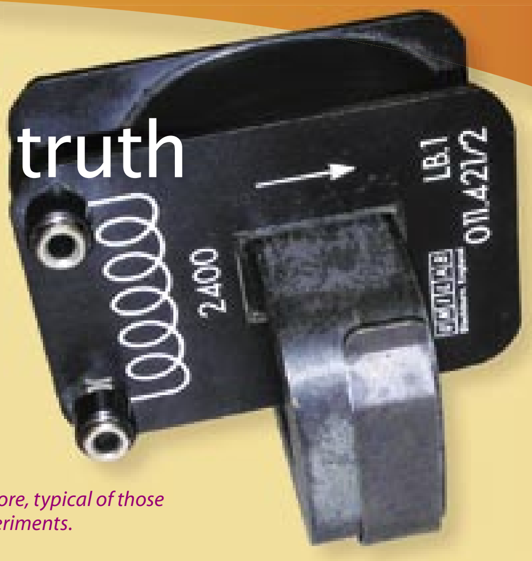

Figure 1 - Coil with core, typical of those used in inductor experiments.

Most teachers are familiar with SSERC's guidance on Van de Graaff generators, most recently updated in Bulletin 223. Recently, we have had a couple of enquiries on shocking pupils with inductor coils, along the lines of, "I've been doing this for years, but is it allowed?" The obvious answer is, "If you don't know, don't do it until you find out." Having said that, there seems to be no readily-accessible information available to teachers on whether or not this is a safe thing to do. What is more, pupils may accidentally shock themselves when working with inductors.

When an inductor is connected to a smooth dc source, a back emf is established that opposes the current. This diminishes with time, with the current eventually reaching a steady state value equal to V/R where V is the supply voltage and R is the resistance of the circuit. This will largely be due to the resistance of the inductor's windings. The time to reach the steady state depends on the circuit resistance and the coil's inductance L. Roughly speaking, it will be around $5L/R$.

When the inductor circuit is broken, a back emf attempts to maintain the current. The circuit resistance is now much larger. If a switch is used to make the break, the resistance will now be of the order of megohms. This has two consequences. Firstly, $5L/R$ is now very small. The current is going to fall to zero in a very short time. Secondly, the back emf will be large. The circuit resistance may have increased one hundred thousand fold. The emf required to sustain the current will increase proportionately, albeit for the aforementioned very short time. We are now in the realms of Van-de-Graaff-generator voltages.

When assessing risk associated with Van-de-Graaff shocks, we looked at the energy stored in the system and applied a safety limit of 500 mJ, knowing that, in practice, the actual spark energy is almost always rather lower. No special pleading should be made for inductors. The safety limit for the spark energy from an inductor should be 350 mJ, the level above which discharges are considered to be a direct hazard to health.

The energy stored in an inductor's magnetic field is given by $\frac{1}{2} L I^2$, where I is the steady-state current. Using manufacturer's data for the inductance, we calculated the energy for two sets of coils (Table 1).

A coil typical of those used in this investigation is shown in Figure 1. In conclusion, a shock from coils such as those above is unlikely to be harmful to a healthy pupil. If using coils other than these types, carry out an energy calculation for yourself, or consult SSERC. Adopt the following control measures:

- Do not shock or expose to the risk of shock a pupil who has a heart condition.

Our Van de Graaff guidance asserts that charging pupils should be limited to volunteers. If you are setting out to deliberately shock pupils, you must ask yourself whether this is an ethical thing to do. What is the educational point? If it is to show that there is a large back emf induced when an inductor circuit is broken, or that energy is stored in a magnetic field, you could do so by using the inductor to strike a neon bulb. It could be argued that the "shock" method is more memorable and therefore more effective. But don't use it as a covert form of corporal punishment.

Table 1 - Energy stored by inductors

Coil	Inductance (H)	Steady state current (A)	Energy (mJ)	Comments
Unilab 60 turn transformer coil with full core.	0.01	8	320	Current taken as maximum available from typical school PSU. This exceeds the rating of the windings by a factor of 4.
Unilab 2400 turn coil with full core.	5	0.2	200	Resistance of windings measured as 70 Ω. Current calculated for PSU set at 12 V.