Tunnel Diode Oscillators for Measuring the Critical Temperature of Superconductors

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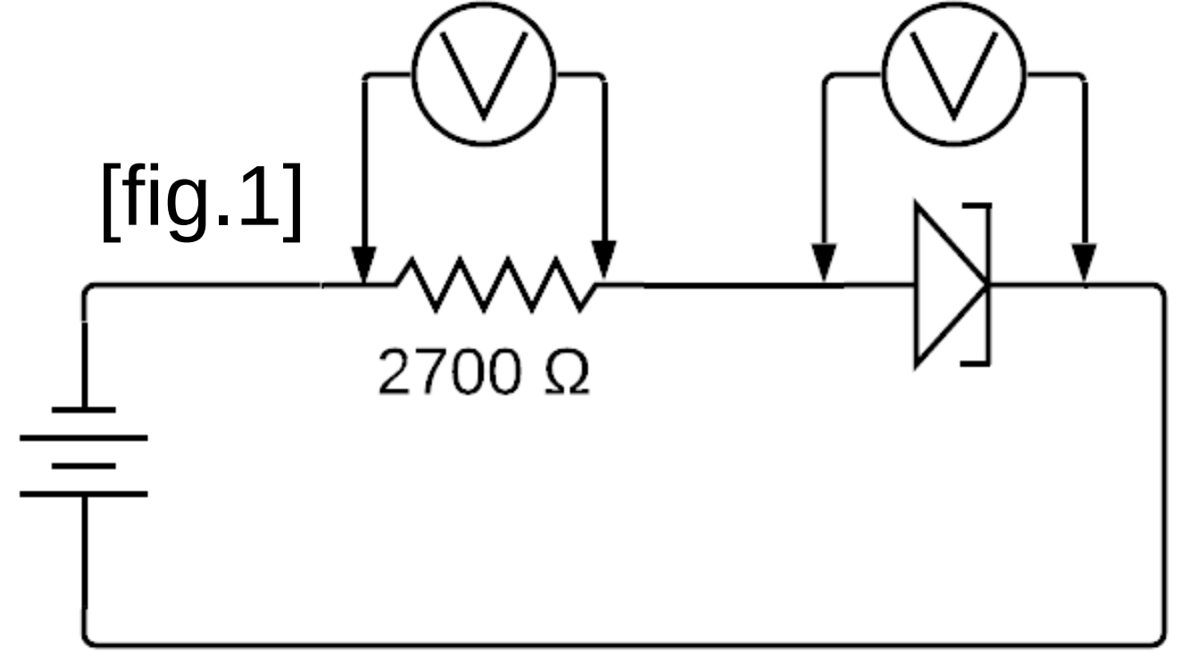
ABSTRACT

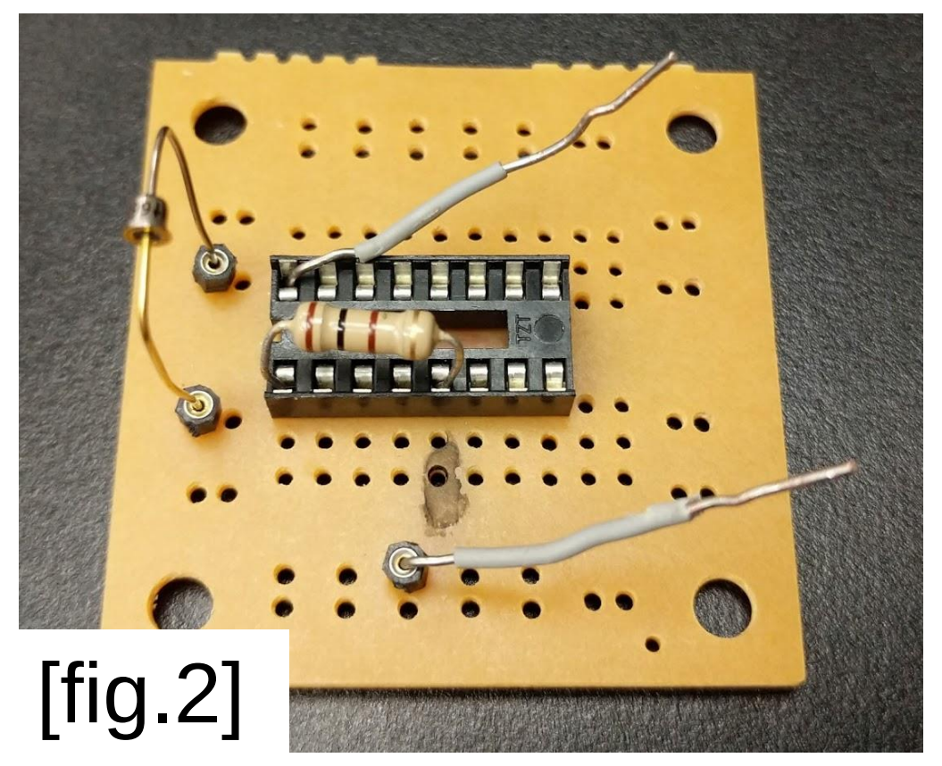
Tunnel diode oscillators can be used to measure the critical temperature of a superconductor by monitoring the frequency of oscillation. In my experiment I have constructed an LC to be used in conjunction with a tunnel diode for a stable oscillation. The tunnel diode keeps the oscillation from damping because of its unique characteristic of negative resistance at certain voltages. In order to use the tunnel diode for this purpose I first measured its IV curve to determine at what voltage it needs to operate. Once this is done, it can be used in the oscillator circuit and set up with the superconductor. The critical temperature of the superconductor is seen as a sudden drop in the graph of frequency of the oscillator as a function of temperature.

TUNNEL DIODES

Tunnel Diodes are a special kind of PN junction diode that have the interesting characteristic of negative resistance for a range of voltages. I measured this range using the circuit in figures 1 and 2 below.

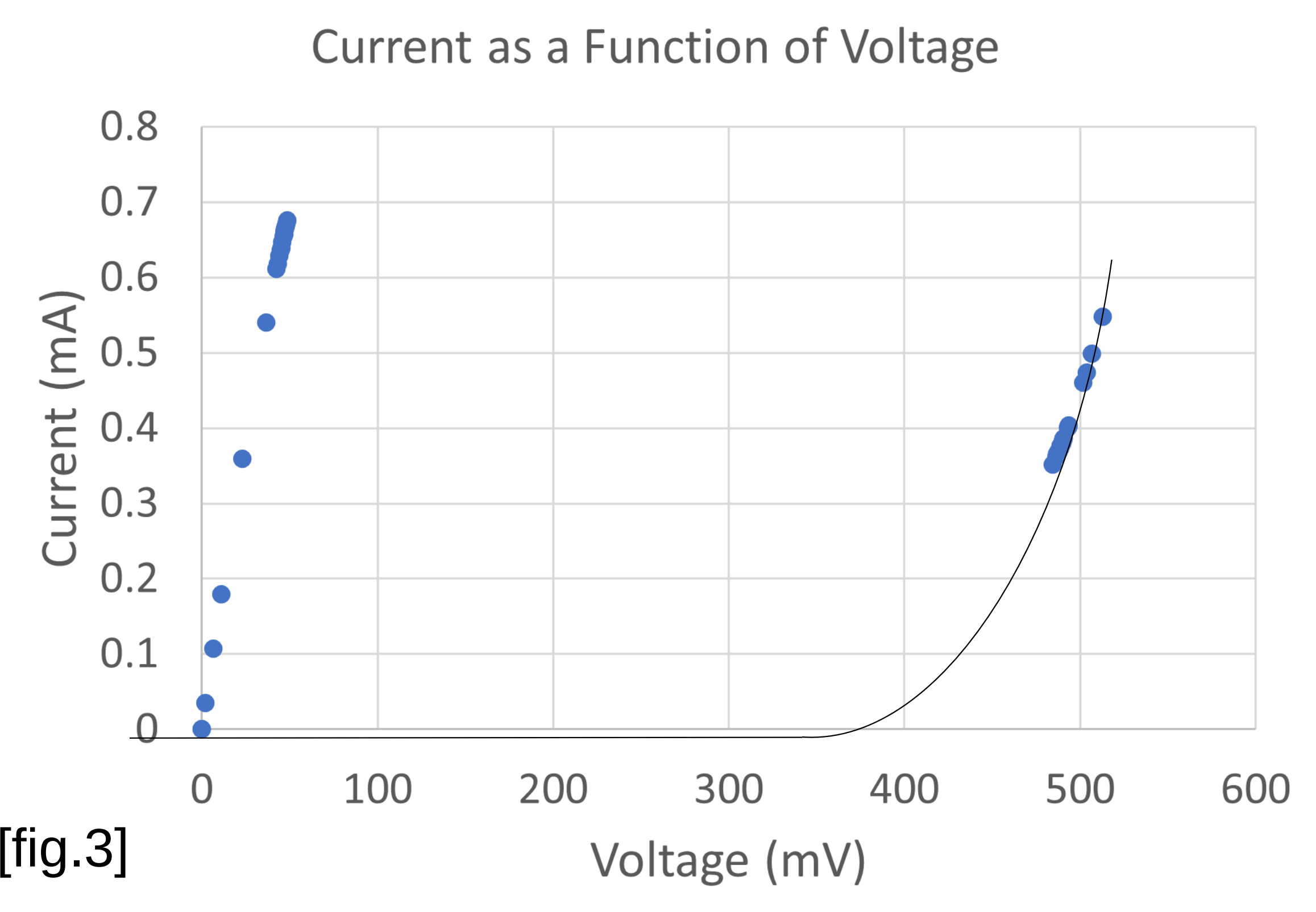
[fig.1]





[fig.2]

Using this circuit, I measured the voltage across each component as I increased the voltage of the source. Using Ohm's Law, I got the current through the circuit and plotted it as a function of the voltage across the diode to get the graph in figure 3.



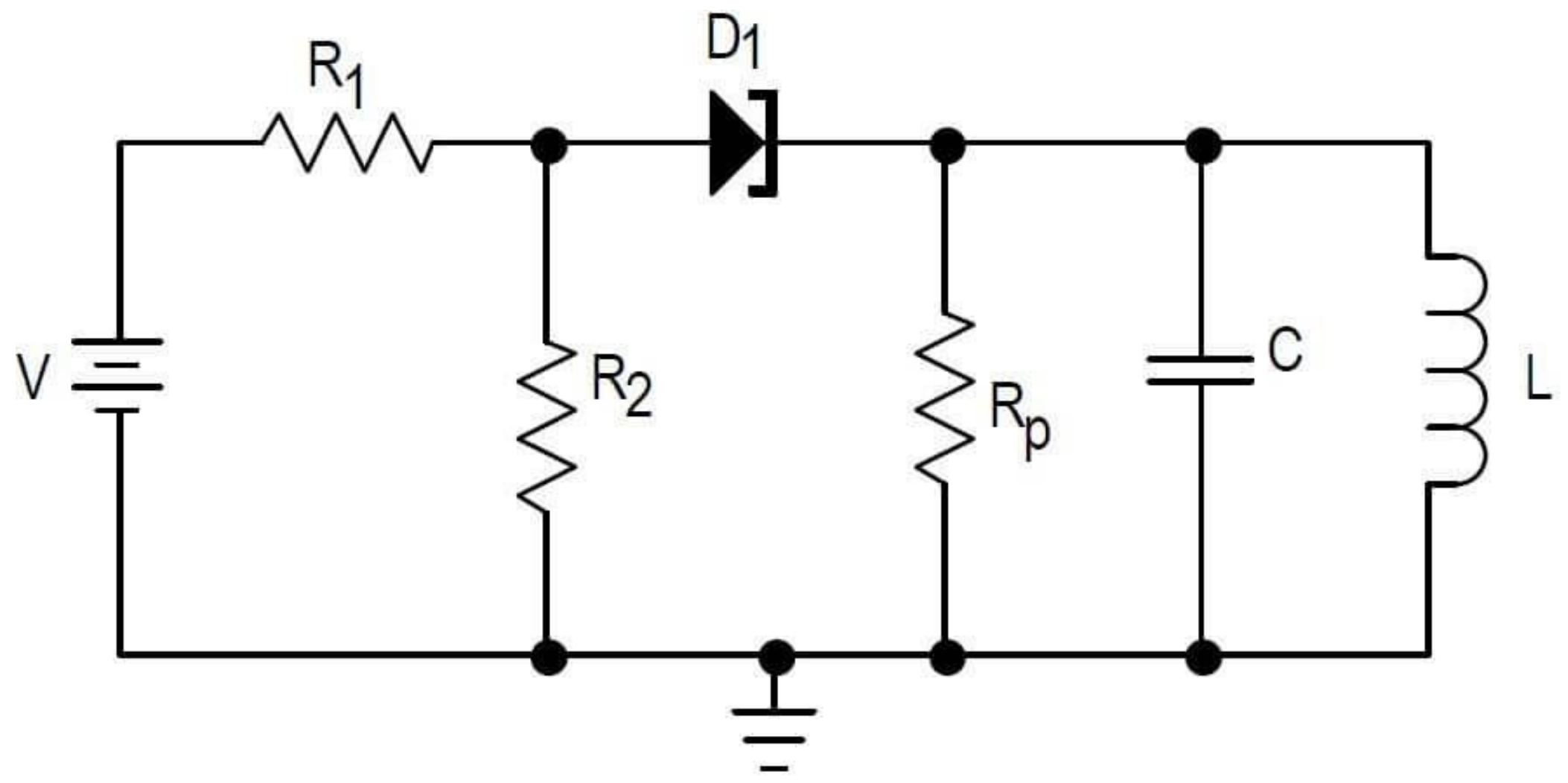
[fig.3]

As the voltage increase across the diode current increases due to quantum tunneling of charges in the diode. However, at a point this tunneling ceases and the diode returns to a normal diode IV curve, shown by the black line, and the circuit now has a lower current. This exhibits negative resistance because $R = \frac{V}{I}$ so for a negative $\frac{\Delta V}{\Delta I}$, R will be negative.

TUNNEL DIODE OSCILLATORS

Using the tunnel diode in its region of negative resistance a tunnel diode oscillator can be constructed as seen in figure 4.

[fig.4]



At its base, the oscillator is made of a tank circuit, an inductor (L) and capacitor (C) in parallel. When the capacitor is discharged through the inductor, this creates an oscillation that is damped proportional to the resistance of the resistor (R_p). However, when the tunnel diode (D_1) is used in the circuit its negative resistance counteracts this resistance and oscillations can continue.

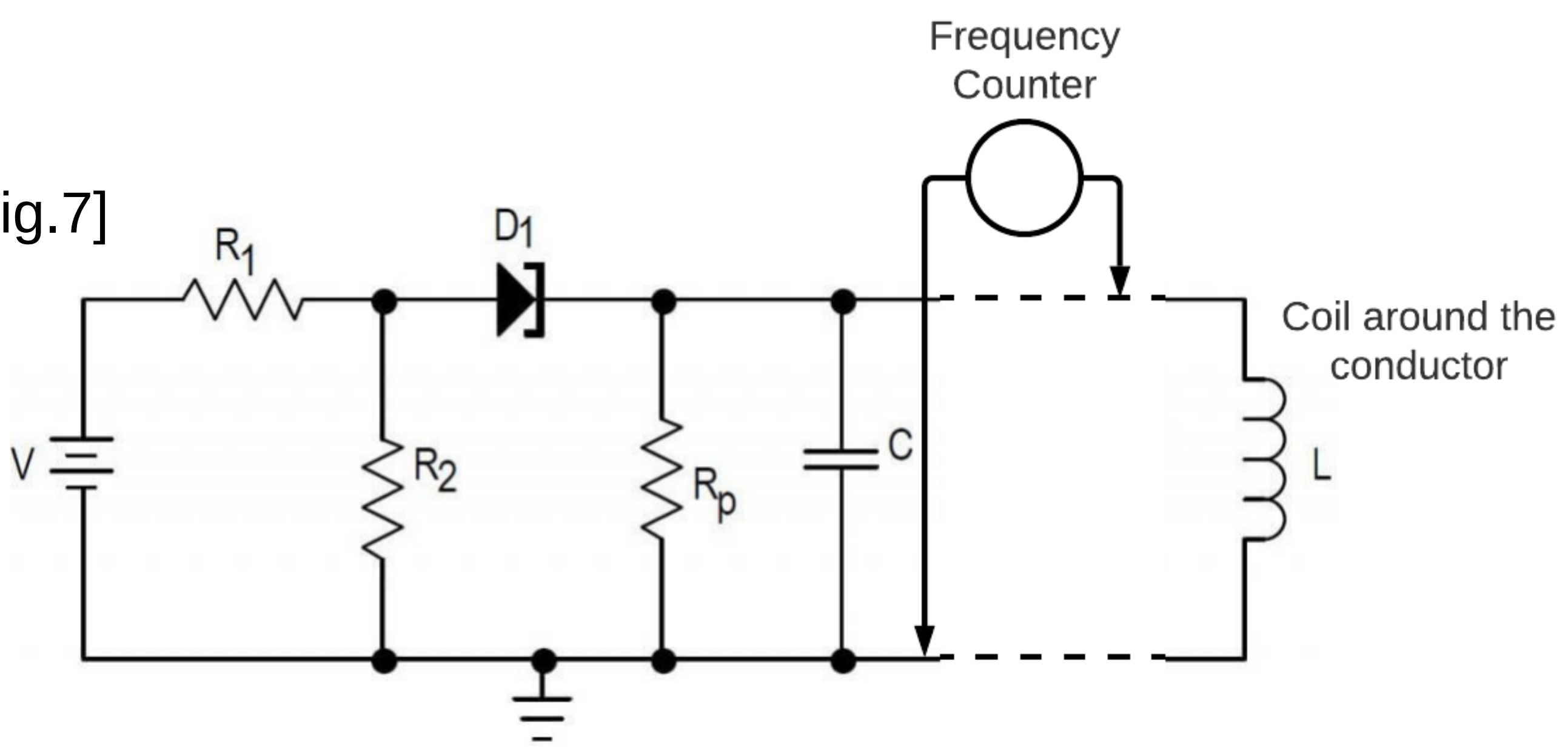
MEASUREING THE CRITICAL TMPERATURE

The resonant frequency of a tunnel diode oscillator is dictated by the tank circuit and its resonant frequency:

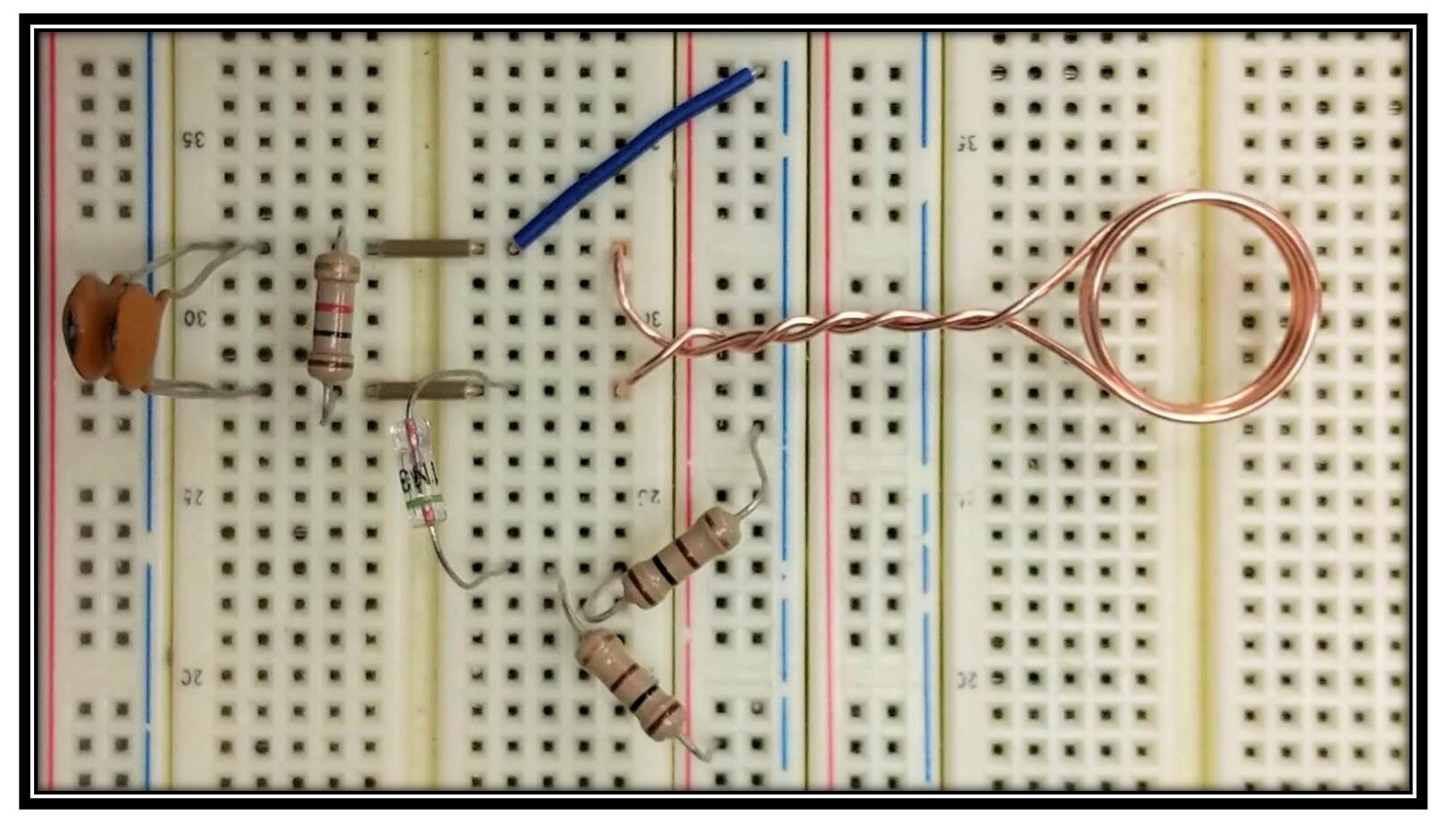
$$f = \frac{1}{2\pi\sqrt{LC}}$$

where L is the inductance and C is the capacitance. With a fixed capacitance, a change in the inductance will change the resonant frequency of the circuit. The circuit in figure 4 is adapted so that the inductor can be coiled around the superconductor sample and a frequency counter is used to measure the resonant frequency of the oscillator as in figure 7. When the superconductor reaches its critical temperature the magnetic field of the inductor will be excluded from the conductor changing the inductance and resonant frequency.

[fig.7]



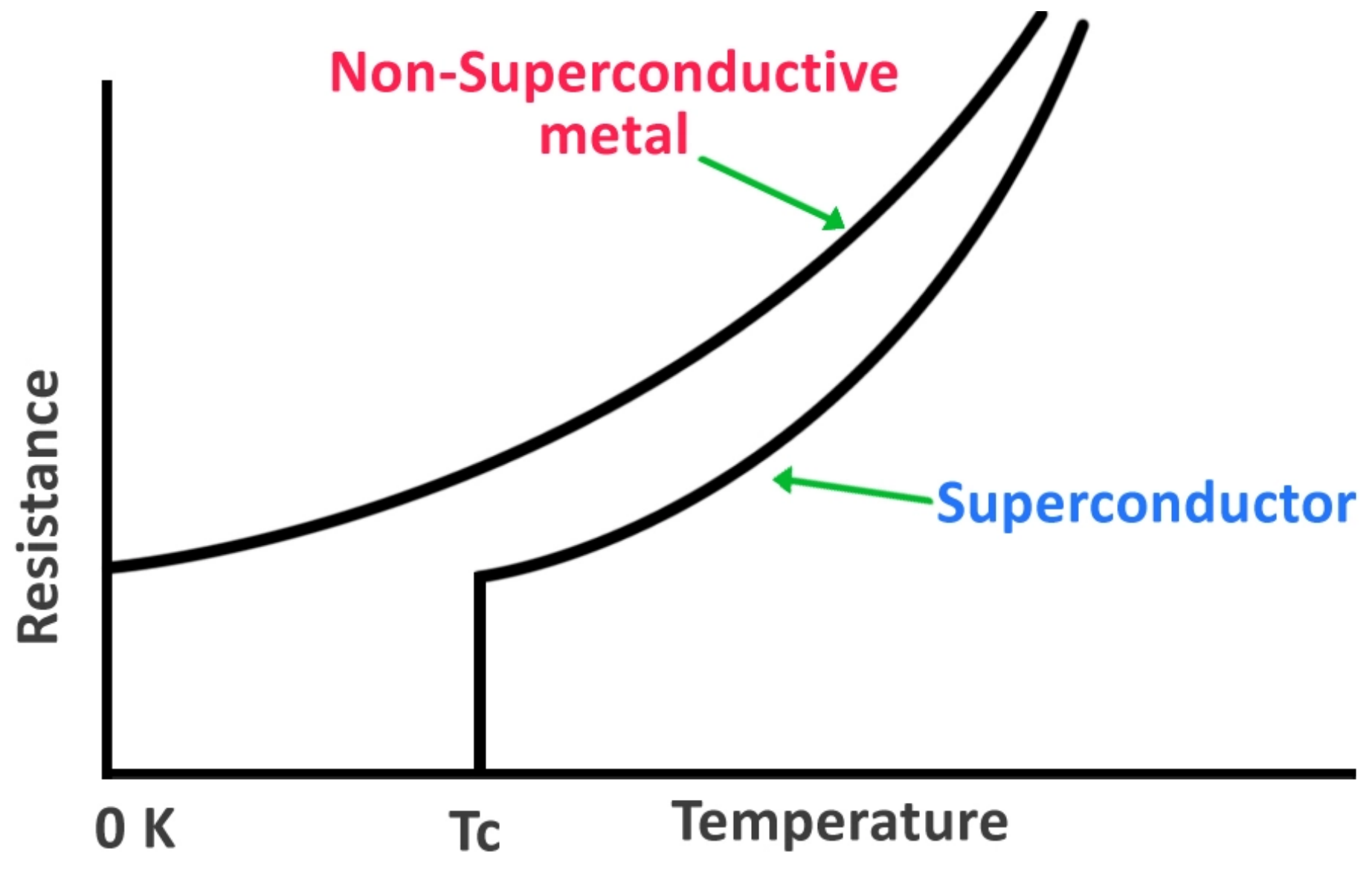
[fig.8]



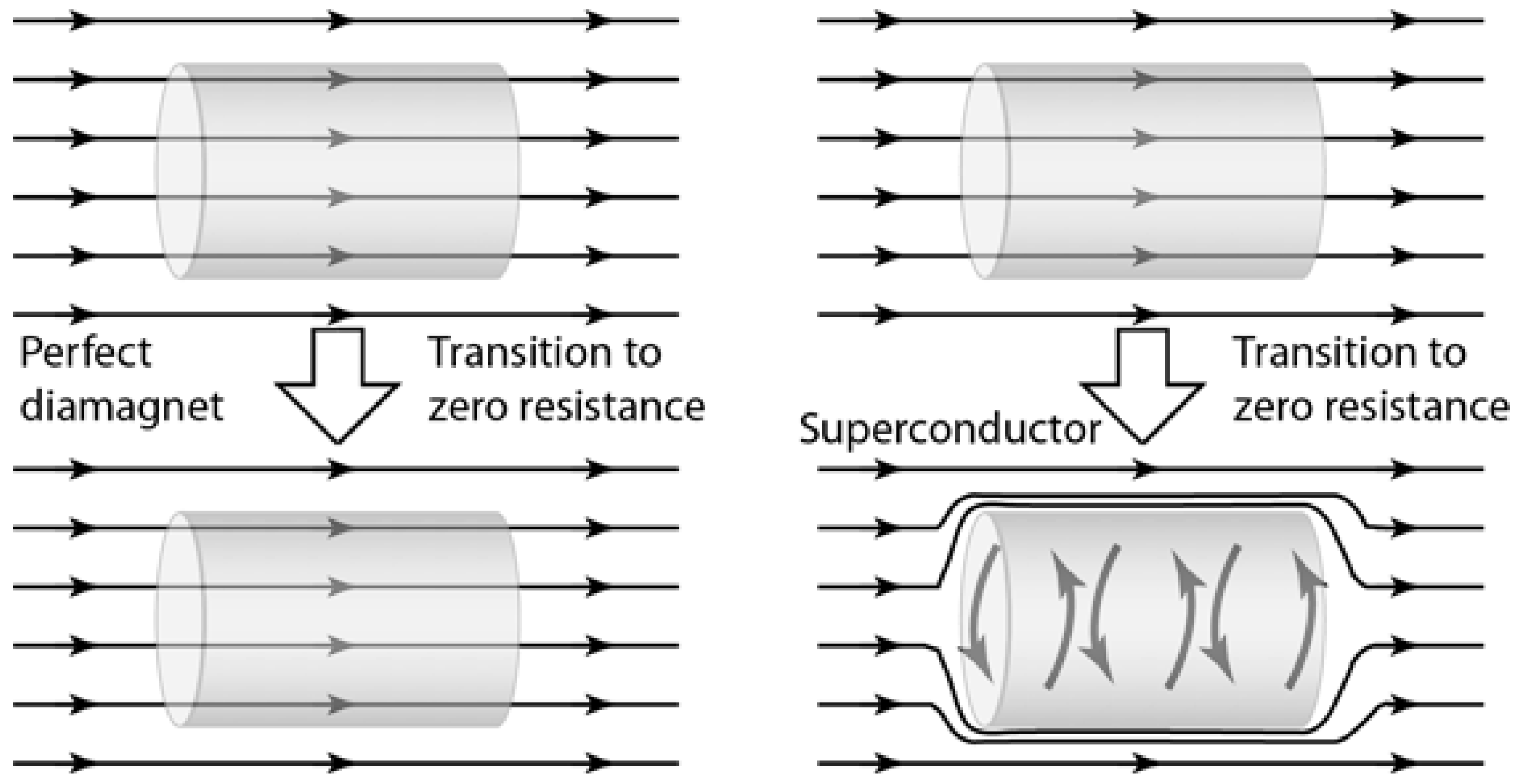
SUPERCONDUCTORS

Superconductors differ from normal conductors because below a certain temperature called the critical temperature (T_C)[fig.5], which is different for each conductor, they allow conducting electrons to be made into what are called Cooper pairs. These pairs occupy the lowest possible energy meaning that they cannot give energy to the conductor and so there is no resistance to the flow. When a superconductor is in the presence of a magnetic field, currents will be generated in it that will oppose the field which cause it to be excluded from the conductor as seen in figure 6.

[fig.5]



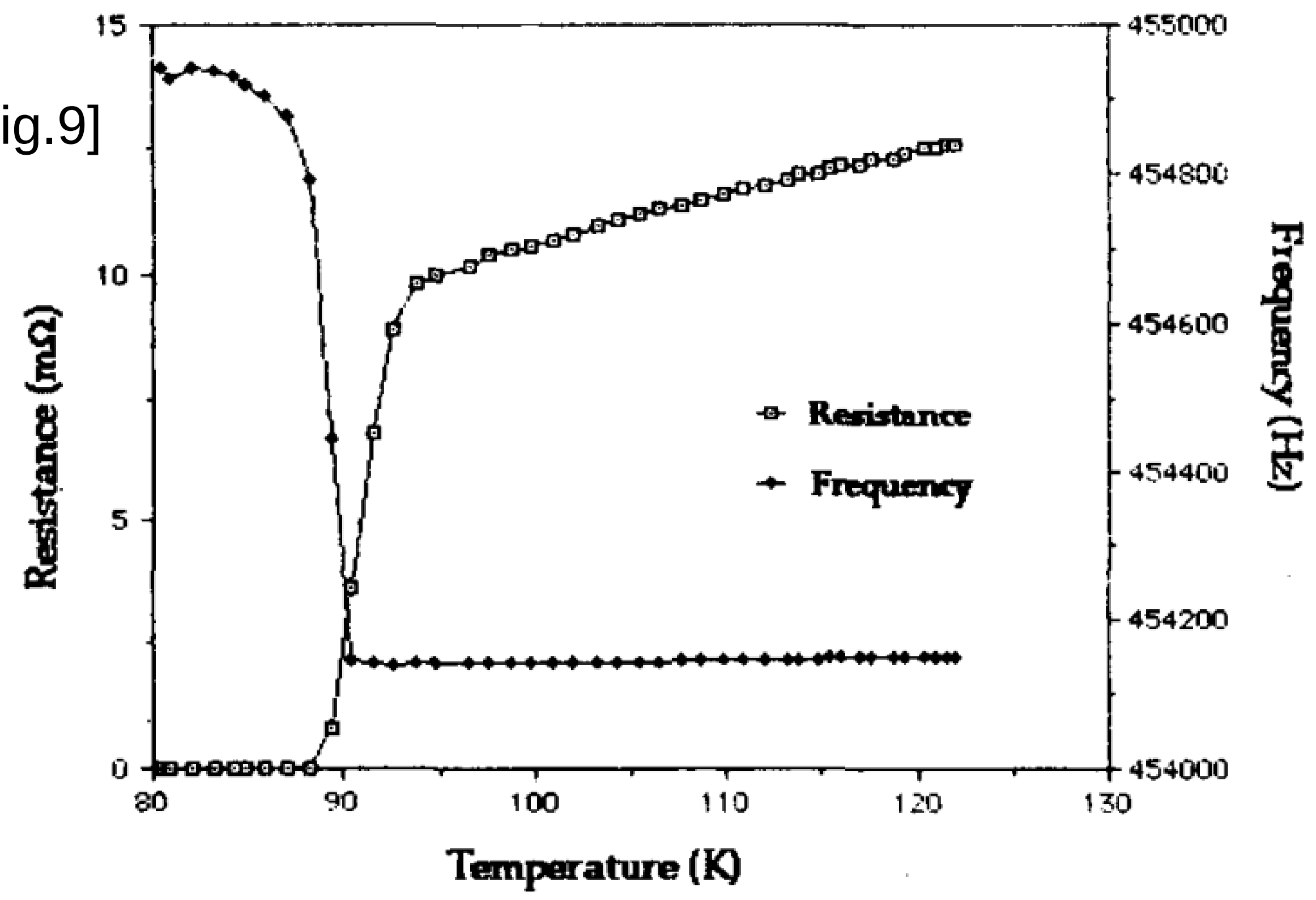
[fig.6]



RESULTS

Using the technique of measuring the critical temperature of a superconductor with the resonant frequency of tunnel diode oscillator I expect to get results like those in figure 9. When the conductor cools to its critical temperature, the resistance will drop to zero and the frequency will increase due to the inductance decrease.

[fig.9]



CONCLUSION

This method of measuring the critical temperature is an almost equally accurate alternative to directly measuring the resistance. While it has complications with the oscillating circuit, it has the benefit of not needing to directly attach to the sample. This is particularly useful for small samples such as those used in high pressure diamond anvil cells. With many of the new superconducting materials being found at high pressures this could be a useful tool.

REFERENCES

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