

EQUIPMENT

THE SET UP FOR THE QUANTIZED HALL EXPERIMENT IS REALLY QUITE SIMPLE IN CONCEPT, ALTHOUGH THE IMPLEMENTATION MIGHT LOOK A BIT COMPLEX. ALL WE DO IS GENERATE A BIG, VARIABLE MAGNETIC FIELD AROUND A SEMICONDUCTOR SAMPLE AND MEASURE ITS HALL RESISTANCE WHILE WE RAMP THE MAGNETIC FIELD. A SIMPLE PIECE OF CONDUCTOR AT ROOM TEMPERAURE AND AT NORMAL MAGNETIC FIELD WOULD JUST SHOW A LINEARLY INCREASING HALL RESISTANCE WITH LINEARLY INCREASING FIELD. A TWO-DIMENSIONAL ELECTRON SYSTEM (AS WE HAVE ESTABLISHED IN OUR SEMICONDUCTOR) AT THE LOW TEMPERATURE OF LIQUID HELIUM AND IN THE HIGH MAGNETIC FIELD OF A SUPERCONDUCTING MAGNET SHOWS STEPS THAT ARE QUANTIZED TO VERY HIGH PRECISSION TO h/ie^2 , WHERE h IS PLANCK'S CONSTANT, e IS THE ELECTRONIC CHARGE AND i IS AN INTEGER.

HERE WE DISCUSS THE EXPERIMENTAL SET UP.

WHAT WE NEED ARE LOW TEMPERATURES, A HIGH MAGNETIC FIELD AND A SPECIAL SEMICONDUCTOR SAMPLE IN IT, OF WHICH WE MEASURE THE RESISTANCE.

THE EXPERIMENT RESIDES IN A STEEL DEWAR TO REACH AND KEEP THE LOW TEMPERATURES REQUIRED FOR THE EFFECT TO OCCUR, BUT ALSO TO PRODUCE THE VERY HIGH MAGNETIC FIELDS VIA A SUPERCONDUCTING COIL.

DEWAR

LEVEL METER

COIL

TO POWER THE COIL WE NEED A POWER SUPPLY AND RAMP

POWER SUPPLY AND RAMP, DIODES, DVM....

TO IMERSE THE SAMPLE WE NEED A SAMPLE HOLDER

SAMPLE HOLDER

TO MEASURE WE NEED CURRENT SOURCE AND DVM

TO VISUALIZE THE DATA WE NEED A COMPUTER

I. Power Supply *TO THE SUPERCONDUCTING MAGNET.*

Current is supplied to the magnet via a 6260B Hewlett-Packard power supply. This power supply is configured to run in current controlled mode—that is, the power supply will vary the voltage until the target current is achieved. The “target current” in this case is dictated by the RAMP GENERATOR. It should be noted that this power supply (and most power supplies, for that matter) do not deal well with inductive loads.

In a purely resistive circuit at constant voltage, the current in the circuit will be equal to V/R . If the resistance is fixed, we can alter the current simply by changing the voltage until the current reaches the desired level. In a purely inductive circuit, however we have (from Faraday’s Law):

$$V = L \frac{dI}{dt}$$

If we change the voltage linearly from $V_1=Vt_1$ to $V_2=Vt_2$, then by integration:

$$\int_{t_1}^{t_2} V(t) dt = \int_{t_1}^{t_2} L \frac{dI}{dt} dt$$

$$\frac{1}{2} V(t_2^2 - t_1^2) = LI$$

$$\frac{V \Delta(t^2)}{2L} = I$$

IF THE COMBINATION OF INTERNAL STABILIZATION LOOPS of the power supply WORKS ON THE ASSUMPTION OF A PURELY RESISTIVE LOAD, this may create an oscillatory behavior in the power supply voltage, and most likely a magnet quench. THEY THINK TIME DOES NOT MATTER (AS IN $V= Ri$) AND YET TIME DOES MATTER (AS IN $V = L di/dt$). SO THEY GET CONFUSED.

II. RAMP GENERATOR

In order for the power supply to increase the current in a linear, controlled fashion, something needs to tell it what current to put out when. This something is the RAMP GENERATOR. On the rear of the ramp generator are two connections of importance: the current shunt, and the control. The control leads should be connected to the POWER SUPPLY. It is important that correct polarity is observed in this connection, else a quench will occur. The current shunt is what allows the ramp generator to operate in a closed loop: the generator tells the power supply to create a certain current, and the current shunt tells the ramp generator if the power supply *HAS DONE* so correctly (there are situations where this control scheme goes awry—see the discussion of inductance under POWER SUPPLY).

There are four controls of importance on the ramp generator:

Ramp rate: This control consists of two knobs. One is a range setting, with positions at 0.1, 1, and 10. *THE UNITS ARE A/SEC* The variable rate knob sets the increment between these numbers. For example, if the range knob is set at 0.1 and the variable rate knob is set to 1, then the ramp rate will be 0.01 amperes per second. *AND IT WILL TAKE 10,000 SEC TO GET TO 100 A. THE SUPERCONDUCTION MAGNET CAN ONLY BE RAMPED AT SPEED LOWER THAN XXXX. OTHERWISE IT WILL QUENCH.*

Voltage limit: In some circumstances, the desired current will necessitate a higher voltage than the power supply *IS ABLE* to deliver. In these cases, the voltage limit control can be used to *LIMIT THE VOLTAGE THAT THE RAMP IS GIVING TO THE POWER SUPPLY*. In this experiment, the currents required are not high enough for this to be a problem.

Current limit: while the voltage limit is not a concern in this experiment, the current limit is of GREAT IMPORTANCE. If the magnet is ramped to a higher field than its rated value, a quench will occur, resulting in possible physical harm to the researcher and damage to the magnet. *SINCE AT SUCH MAXIMUM FIELD THE MAGNET HAS TO DISSIPATE MAXIMUM ENERGY [AND IT GOES LIKE B^2 , REMEMBER], THIS COULD POTENTIALLY BE DISTRUCTIVE TO THE MAGNET, WHICH COSTS ABOUT \$5,000!* The magnet in use is rated to 69.6 Amperes, however the current limit control is not exactly reliable. It is recommend to set this control to around 65 amperes on the first ramp up, and when the current limit indicator (the red LED next to the knob) lights up, *SLOWLY* increase the current limit until a value of no more than 69.6 appears on the DVM *THAT MEASURES THE CURRENT AND HENCE THE MAGNETIC FIELD*.

POLARITY SWITCH:

The power supply used in this experiment is unable to reverse polarity: the positive output is always positive, and the negative output is always negative. However, it is sometimes desired that the field of the magnet be reversed, hence the polarity switch. The switch controls three relays that reverse the polarity of the current. The relays are located in the energy *absorber*, *which is a circuit used to insure safe magnet operation*. More importantly, the polarity switch also monitors the current in the magnet circuit, and will not allow the polarity to be switched if said current is non-zero, *OTHERWISE THE RAPID di/dt THROUGH THE MAGNET MAY CREATE DAMAGE* (try it—at some non-zero current, flip the polarity switch. An alarm will sound, and the polarity will remain stubbornly unchanged).

ENERGY ABSORBER:

The Energy Absorber contains the relays necessary to flip polarity, three diodes and two thyristors. The three diodes serve to give the power supply some resistance, because, as previously mentioned, the power supply cannot handle a purely inductive load.

The “energy absorption” is accomplished by means of the two thyristors (also known as silicon controlled rectifiers, or SCRs). SCRs are basically solid state relays—on a given signal, they make a connection, in this case to ground. A small monitoring circuit (the small boards next to the thyristors) will detect a quench in the magnet (a large voltage develops in the circuit when this happens). Rather than have all the current flow back into the power supply (and possible damage it), the thyristors will fire and sink the current to ground, *THROUGH AN APPROPRIATE RESISTANCE TO AVOID DAMAGE TO THE COIL.*

SUPERCONDUCTING MAGNET:

The QHE experiment utilizes an 8 Tesla superconducting solenoid. By shorting the coil with a superconducting shunt, any current present in the coil will circulate indefinitely, thus maintaining an extremely stable, perpetual magnetic field. However, the inclusion of this superconducting shunt creates a problem: any current we attempt to put through the coil will simply travel across the shunt, bypassing the coil, and thus not creating a magnetic field. To solve this problem, there is a small resistive element in close proximity to the shunt, known as the PERSISTENT SWITCH. When current runs through this resistive element, it heats up, and raises the temperature of the shunt above the critical *SUPERCONDUCTING* temperature. The shunt is no longer superconducting, and current will flow through the coil. Once the desired field is created, we can turn off the persistent switch, and the magnet will enter persistent mode, where current is trapped in the coil/shunt assembly. It is of great importance that the persistent switch be turned on *ONLY* when the output of the power supply matches the current already in the magnet. Otherwise, the attempt to change the current so rapidly will result in a large back EMF. The output of the power supply will be dropped entirely across the shunt, quite possibly destroying it, and quenching the magnet in the process.

DIGITAL VOLT METERS (DVMs):

Two DVMs are used in the QHE experiment. The FIELD DVM measures the voltage drop across a 1 m Ω resistor located in the ENERGY ABSORBER. The current in the magnet can then be read directly off the DVM (just multiply by 1000, or simply ignore the exponent). In order to determine the field, one needs only to multiply the current by 0.1149, the current/field ratio of this particular magnet.

The RESISTANCE DVM is used to measure the Hall voltage, or the magnetoresistance of the sample, depending on what wiring geometry is used.

CRYOSTAT:

The magnet is contained within a 10L helium dewar. There are three layers to the dewar:

- a vacuum layer to thermally isolate the central helium section
- a liquid nitrogen jacket that absorbs *MOST H α E T radiation FROM THE ENVIRONMENT.*
- the helium section itself, which contains the magnet

This system is well suited to holding helium - the Dewar is capable of holding the magnet at helium temperature for upwards of 5 hours.

MAGNET INSERT:

The magnet is suspended in the helium by an insert that also contains a guide tube, which serves to guide the PROBE into the magnet bore, and the *HELIUM LEVEL METER*. A series of baffles above the magnet prevents radiation from reaching the liquid helium.

HELIUM LEVEL METER:

The level meter is no more than a 24" piece of superconducting wire. The portion of this wire that is immersed in helium will be superconducting, while the remainder of the wire has some non-zero resistance. Thus the total resistance of the wire serves to give an indication of how much helium remains in the Dewar. The superconducting wire is attached to a meter that translates the resistance detected into a percentage value. The wire is mounted on the insert in such a way as to indicate zero percent when the helium level is just above the magnet. This way, the experiment can be run to zero percent without the magnet quenching.

PROBE:

The switchbox mounted on one end of the probe allows for electrical contact to be made to the sample. Each BNC connector has a corresponding grounding switch. All switches should be set to ground before any connections are made or broken, *OTHERWISE ONE IS LIABLE TO INTRUDUCING TRANSIENT VOLTAGES WHICH CAN DAMAGE THE SAMPLE.*

On the other end of the probe is a brass assembly that protects the sample. To change the sample, unscrew the brass fitting to expose the sample holder—the small black phenolfiber mount. Care should be taken when re-attaching the brass fitting such that the sample holder pins are not damaged.

If the sample is changed mid-experiment, it must be carefully dried before reinsertion into the helium. When the probe is initially removed and exposed to air, moisture will rapidly begin to condense upon it. If the probe were to be reinserted without drying, this water would freeze, possibly cracking or otherwise damaging the probe. It is best to warm the probe up in an atmosphere of pure (*DRY*) nitrogen to minimize the amount of moisture that condenses on it.

SAMPLE POWER SUPPLY:

This unit supplies the current that will flow through the sample itself. We want the current to be constant, even though the resistance of the sample will change as we ramp the magnet. To do this, we supply a constant voltage from a battery and put it through a resistor that has a resistance several orders of magnitude greater than the average sample resistance. That way, when the sample resistance changes due to magnetic field, the percentage change in the total circuit resistance will be minimal. For example, if the sample resistance is around 10 k Ω and the load resistance is 1 M Ω , a 10% change in the sample resistance (a change of 1 k Ω) corresponds to a total load change of a thousandth of a percent.