Electronic Properties of Materials

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Lab Section: A, Wednesday 11/23, 8AM
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Objectives:

The main objective of this lab is to understand the conductivity properties of materials by examining insulators, conductors, and semi-conductors and how their conductivities are affected by temperature changes. At the same time, inspect the correlation between impurities and electrical resistivity.

Experimental Procedures:

PART A: Given five different copper samples with different impurities, measure the resistivity (R) of each sample in liquid nitrogen, dry ice, ice water, room temperature water, and boiling water.

PART B: Given a germanium sample, measure and record the cross-sectional area and length. Measure the resistance of the germanium sample at 200˚K, 273˚K, and 373˚K, as well as 7 different temperatures between 273˚K and 373˚K. Remember to zero ohmmeter for each measurement and to cool only with de-ionized water.

PART C: Given a furnace containing a crucible with polycrystalline NaCl, attach the electrodes to the measuring terminals of the bridge. Measure the resistivity of the specimen in the range from 400˚C to 770˚C at intervals of 10˚C. (Beyond this is difficult because of the melting point at 801˚C)

As the specimen begins to cool, measure the resistivity of the specimen in the range from 400˚C to 770˚C at intervals of 10˚C.

Experimental Results:

Table 1: Resistivity of Cu in liquid nitrogen, dry ice, ice water, room temperature water, and boiling water

	Resistivity (milliohms)				
Cu Sample Number	**77˚K (Liquid Nitrogen)**	**200˚K (Dry Ice)**	**273˚K (Ice Water)**	**298˚K (Room Temp)**	**373˚K (Boiling Water)**
11	0.28	0.46	0.68	0.70	0.86
12	0.42	0.62	0.77	0.82	1.03
13	0.29	0.36	0.49	0.52	0.59
14	1.10	1.50	1.75	1.85	2.10
15	1.15	1.45	1.65	1.75	1.90

This table shows various resistivities of five different Cu samples—differing in impurity amount—at five different temperatures. The resistivity is measured in kiliOhms.

Table 2: Resistivity of a Germanium semiconductor

Dimensions = .693 in x .127 in x .77 in

(˚K)	197	274	328	333	338	343	348	353	363	373
(kOhm)	110.000	8.300	0.393	0.339	0.270	0.223	0.184	0.137	0.101	0.087

A measure of resistivity of Germanium in kiliOhms.

Table 3: Resistivity of NaCl for heating

Temp (K)	R (kΩ)
400	60.00

410	48.00
420	38.00
430	32.00
440	26.00
450	22.00
460	18.00
470	14.00
480	12.00
490	11.00
500	9.50
510	8.40
520	7.30
530	6.40
540	5.60
550	4.80
560	4.40
570	3.90
580	3.40
590	3.00
600	2.80
610	2.40
620	2.00
630	1.80
640	1.70
650	1.60
660	1.48
670	1.30
680	1.12
690	1.00
700	0.90
710	0.77
720	0.67
730	0.58
740	0.51
750	0.40
760	0.33
770	0.26

Resistivity of a polycrystalline NaCl at 10˚K intervals between 400˚K and 770˚K in kiliOhms.

Table 4: Resisitivity of NaCl for cooling

Temp (K)	R (kΩ)
0.14	770
0.20	760
0.29	750
0.37	740
0.41	730
0.49	720
0.58	710
0.67	700
0.77	690
0.83	680
0.98	670
1.00	660

1.10	650
1.25	640
1.40	630
1.55	620
1.80	610
2.00	600
2.20	590
2.45	580
2.90	570
3.20	560
3.60	550
4.20	540
4.70	530
5.30	520
6.10	510
6.80	500
8.00	490
9.30	480
10.60	470
12.40	460
14.80	450
16.00	440
20.00	430
23.00	420
28.00	410
34.00	400

Resistivity of a polycrystalline NaCl at 10˚K intervals from 770˚K to 400˚K in kiliOhms.

Discussion:
Part A

Question 1

Rank the five specimens in order of purity, and give ρr for each specimen in micro-ohm-cm.

The resisitivity due to impurities is called the “residual” resistivity. This value is usually constant over temperature. In this case, the “residual” resistivities are given and they can be ranked in ascending “residual” resistivity and increasing amount of impurity as follows:

Cu 11, residual resistivity = .692 micro-ohm-cm
Cu 12, residual resistivity = 1.22 micro-ohm-cm
Cu 13, residual resistivity = 1.55 micro-ohm-cm
Cu 14, residual resistivity = 1.79 micro-ohm-cm
Cu 15, residual resistivity = 2.40 micro-ohm-cm

Question 2

To what precision can you verify Matthiessen's rule? To answer this question, consider how the resistivity changes with temperature for a fixed concentration of impurities, then how the resistivity changes with impurity concentration when the temperature is fixed.

We can verify Matthiessen’s rule only to a relative precision, which is that between each sample. Besides that, our precision in verifying Matthiessen’s rule is limited by our equipment and time since we cannot get the temperature to the exact value needed with the liquid nitrogen, dry ice, etc.

We can only assume that they are at their tabulated temperatures.

With a fixed concentration of impurities, the “residual” resistivity remains constant. The total resisitivity is only changed by the changing “thermal” resistivity. When the temperature is fixed and the concentration of impurities variable, the only change is in “residual” resistivity. However, “residual” resisitivity is constant. This is true to Matthiessen’s rule.

Question 3

Would you expect ρ to increase or decrease as T is increased through the melting point? Why?

Temperature increased through the melting point would cause a change in physical state, and thus a change in microstructural properties. Because the lattices would break down as the sample transitions to a liquid there will be more impurities. As a result, the residual resistivity is actually changing to increase resistance as more impurities are created. In addition, the increasing temperature increases resistance because it increases collisions with imperfections.

Question 4

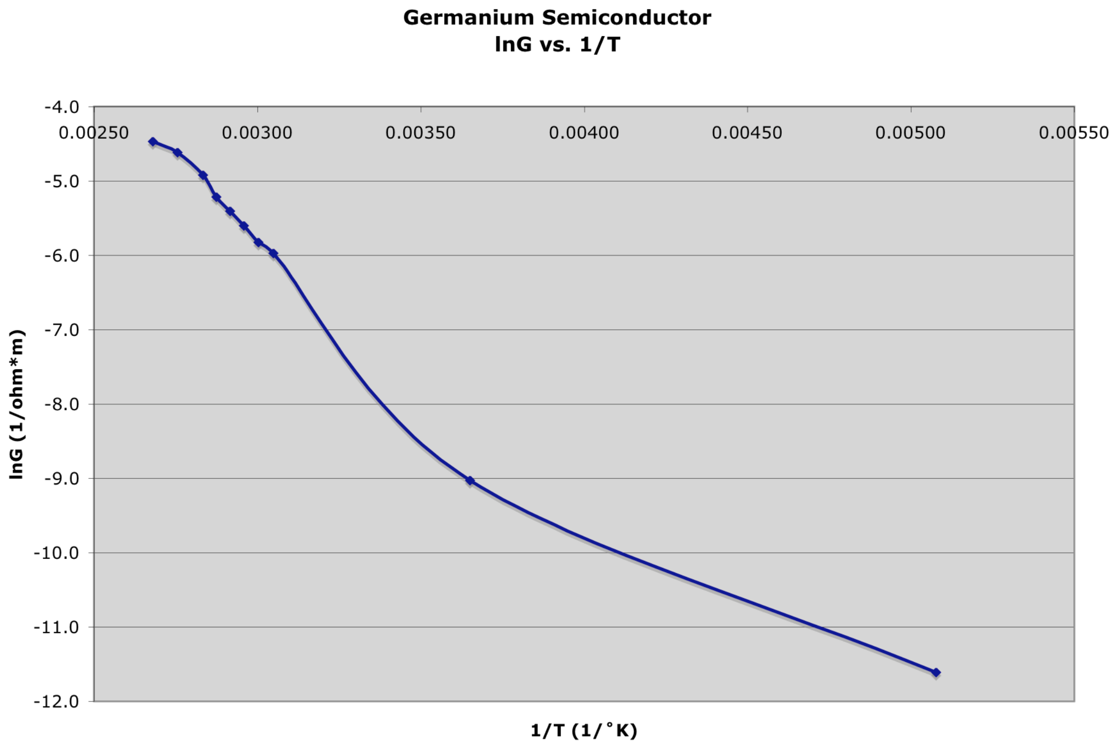
If you dope a metal A with another metal B where $\rho B < \rho A$, do you expect the resistivity of the alloy to increase or decrease? Why?

One would expect the resisitivity of the alloy to decrease from that of metal A, but in fact the resisitivty **increases**. This is because adding another component always increases resistivity by adding more impurities. The lowest resistivity one can obtain is with pure B.

Part B

Question 5

Plot ln(G) versus 1/T for the semiconducting sample studied in this lab.



Question 6

Over what temperature range, if any, does your sample behave as an intrinsic semiconductor?

From our graph it seems that our sample does not behave as an intrinsic conductor. However, the region from .0025-.0035˚K may act as our intrinsic region, which corresponds to 273˚K to 373˚K.

Question 7

What is the energy gap for your sample? Compare with published literature values and cite your sources.

E_g = -slope*2k = 1.446×10^{-19} J * (1eV / 1.602×10^{-19} J) = .9 eV (Values from lecture)
E_g of pure Ge = .661 eV. (2)

This gives us a %error of 36% as compared with the literature value of the energy gap of germanium.

Question 8

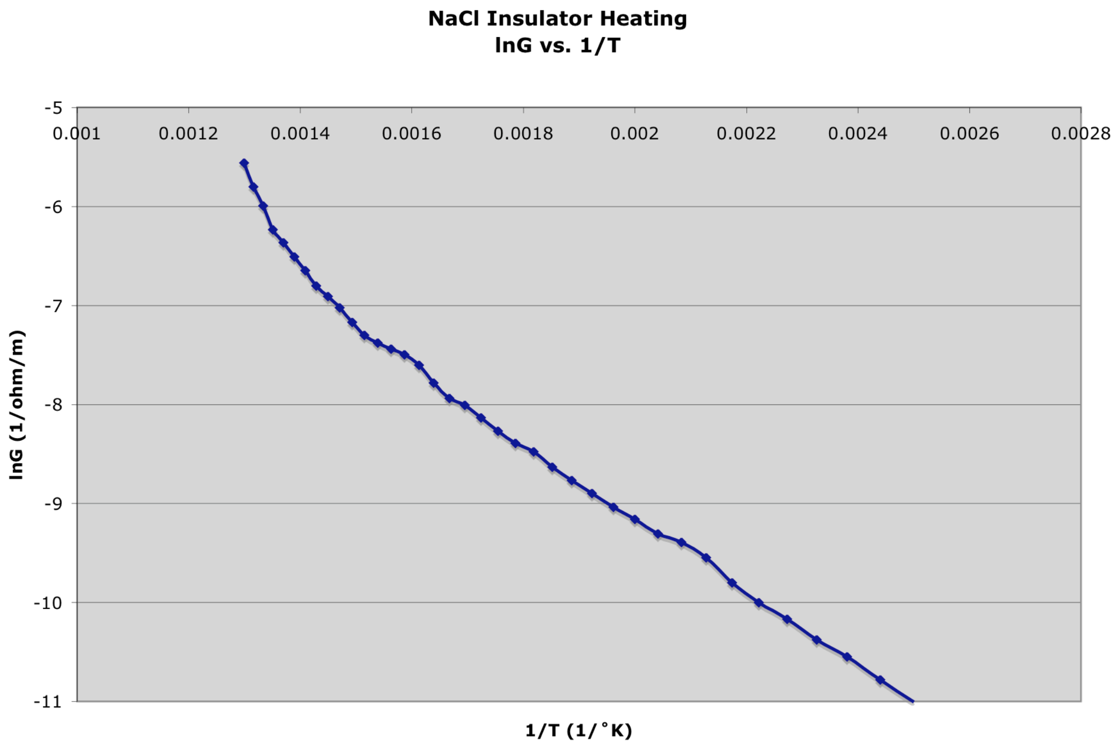
Predict the resistance at 150°C of your sample.

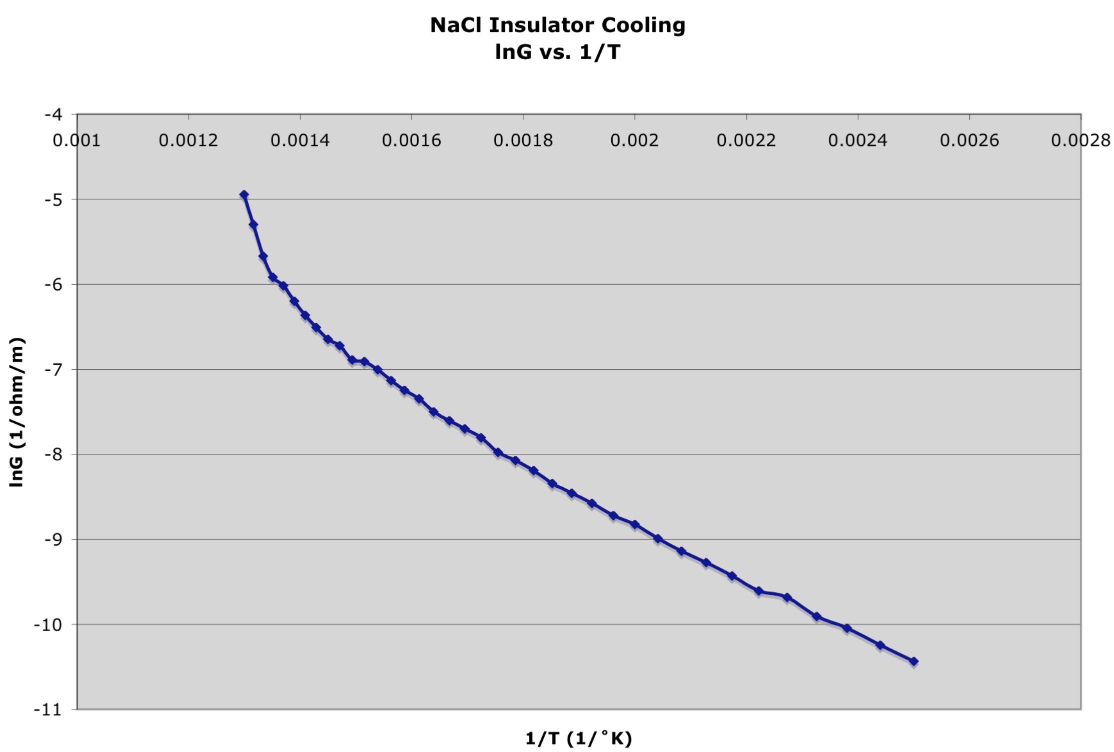
At 150˚C = 423˚K, which is .0024 1/˚K. Plugging this into our equation: lnG = ln(FC)-Eg/2kT; we get approximately 12 Ohms.

Part C

Question 9

Plot ln(G) versus 1/T for the insulator sample studied in this lab.





Question 10

What is the temperature corresponding to the change in slope of the ln (G) vs 1/T plot? If you don't observe any change in slope, what does that mean?

The change in slope is a gradual one and no dramatic change is readily apparent. However, at about .0015 1/˚K is the greatest slope change by estimation. This corresponds to 667˚K.

Question 12

Do you think that conductivity measurements could be used as an index of purity in ionic crystals? Discuss.

Yes, because conductivity increases with an increase in impurities in ionic crystals, and vice versa. This value is constant since impurities don't change with constant temperature. As a result, conductivity can be normalized to reflect purity in ionic crystals. However, one must take into account the effect of temperature. Residual resistivity is constant, but not thermal resistivity and as a result, changing temperature means different resistivity and therefore, different conductivity.

Conclusion:

As a result of this investigation, the following conclusions can be drawn:

1. In conductors, resistivity is directly proportional to the impurities present.
2. In semiconductors, there are extrinisic and intrinsic behaviors. The intrinisic behavior may not be readily apparent due to impurities. In general, intrinsic behavior is exhibited at higer temperatures.
3. In insulators and semiconductors, resisitivity is inversely proportional to the impurities present.
4. Conductivity is based on energy gaps. For insulators this is greater. For semiconductors, the energy gap is relatively small, allowing it some conductivity. For conductors, the valence band is partially filled, corresponding to conductivity.

References:

1. James F. Shackelford, *Introduction to Materials Science for Engineers*, 6th Edition, Prentice Hall, Upper Saddle River, New Jersey (2005).
2. http://www.ioffe.rssi.ru/SVA/NSM/Semicond/Ge/bandstr.html