Condensed Matter Physics
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Lecture - 37
Semiconductors - Worked Examples

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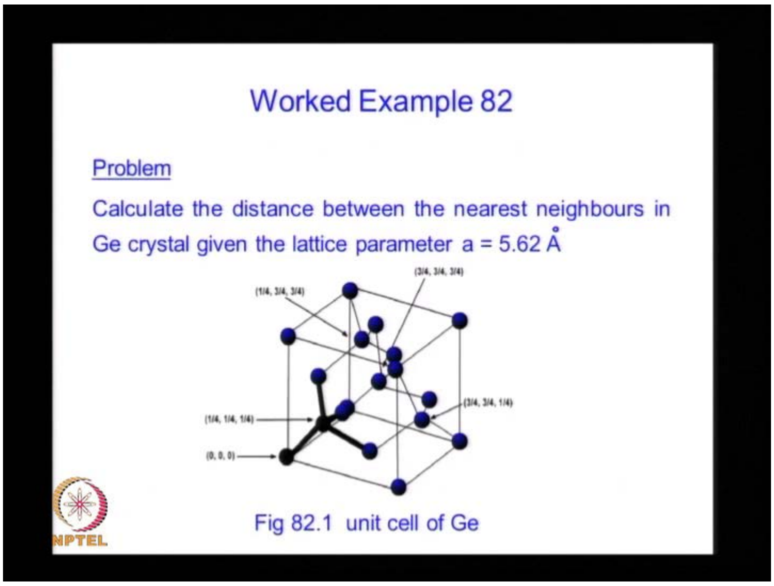

Today we will solve some problems on the topic of semiconductors, which we discussed the first problem concerns.

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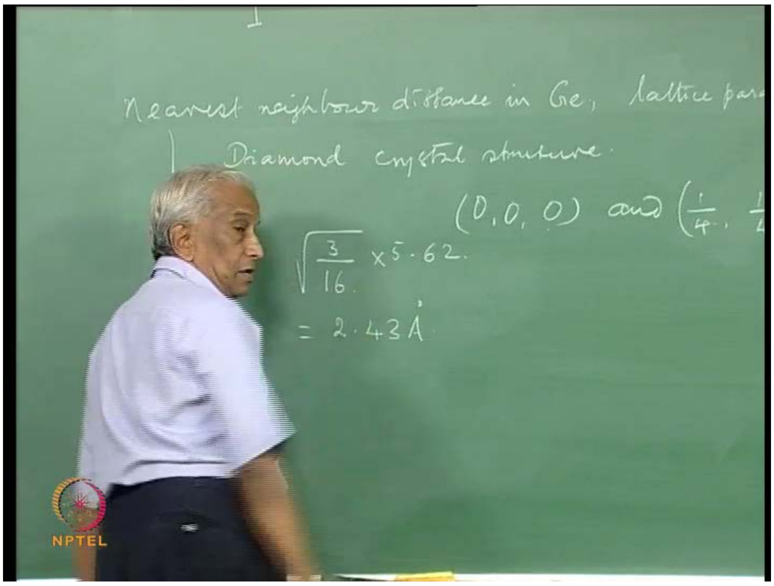

The calculation as a distance between near neighbours in their germanium crystal whose lattice parameter is given noise 5.62 Armstrong's germanium. And silicon both have a cubic unit cell in which the structure is that of diamond, which is shown in the figure with the atoms at noise the origin which is at the vertex of a cube at one vertex of the cube 0 0 0. And then at a distance of one fourth one fourth one fourth along the body diagonal atoms are at these points noise this is the basic problem in the unit..

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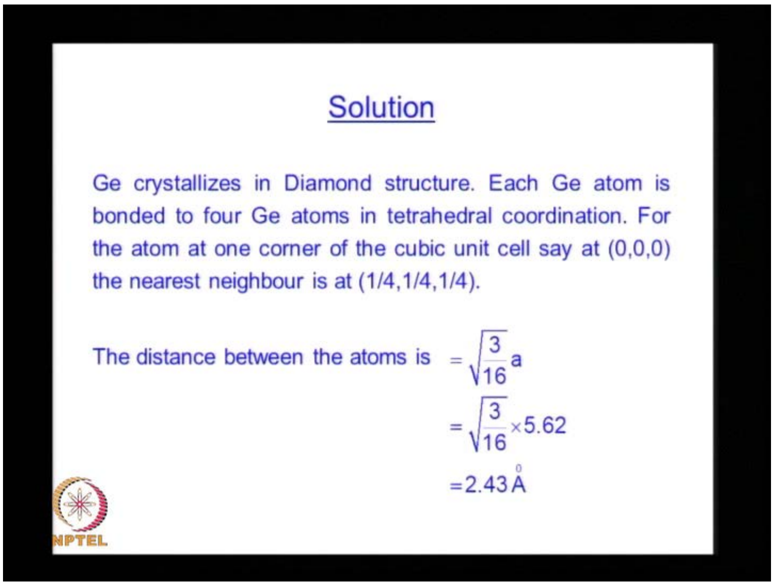

So, this is the unit cell which is shown in figure and we have to simply use geometry and distance which is asked is just root of three by root three by 4, which is root of 3 by 16 times 5.62. That is the distance required between the atom at 0 0 0 and the atom at one fourth one fourth one fourth, and that works out to be two point four three Armstrong's having done.

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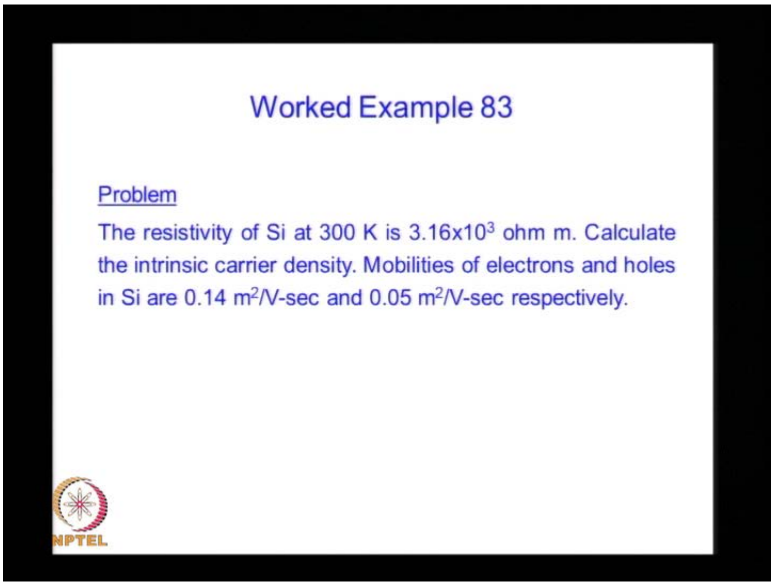

The geometrical calculation the crystal structure calculation. We now pass on to the calculation of the intrinsic carrier density.

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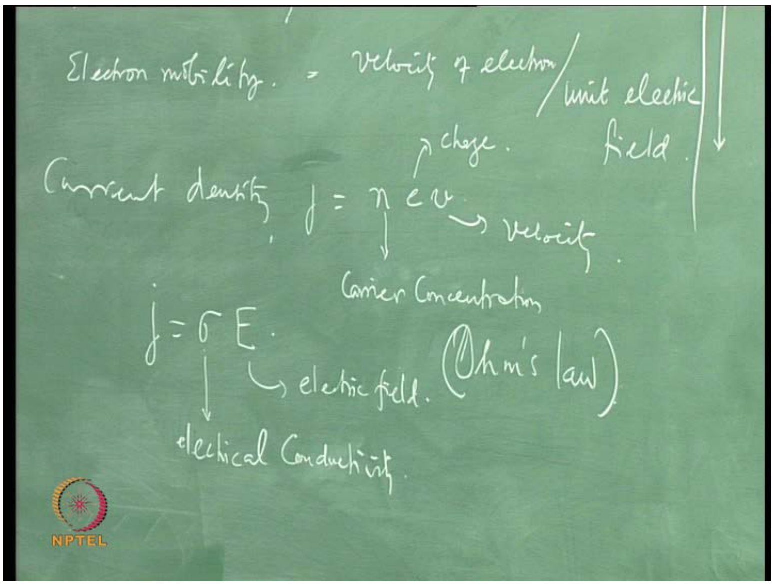

In silicon which is another well-known semiconductor we are given that the intrinsic resistivity at three hundred k is given as 3.16 into ten to the power three ohm metre. So, we are also told that the electron mobility well I do not think we have discussed the concept of mobility. So, far let me introduce the definition of mobility is the velocity of electron per unit electric field, we all know that the current density is in general given as j is n e v, where n is the carrier concentration and e is the electronic charge v is the velocity. So, and we also know that this current density is related to the electric field via the conductivity this is the electric field, and sigma is the conductivity electrical as we all know this is just ohm's law.

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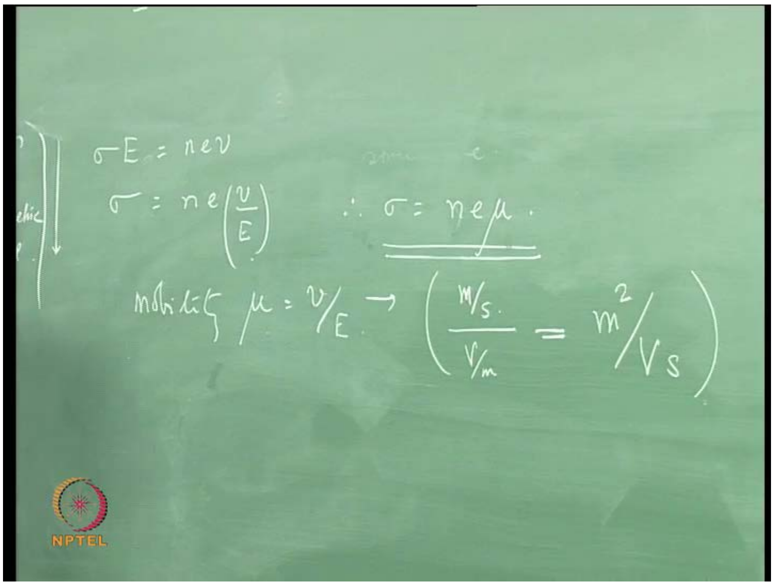

So, because of these we can write n e v is sigma e and therefore, sigma is n e v by e and it is this quantity which we have defined as the mobility. Therefore, sigma is n e mu this is a very basic relationship, which gives the electrical conductivity in terms of the carrier concentration the charge. And the electron mobility and in this problem we are given that the electron mobility in silicon at three hundred k is 0.14 metre square per volt second the unit of mobility is velocity is metre per second, and the electric field is volt per metre therefore, this is metre square per volt second.

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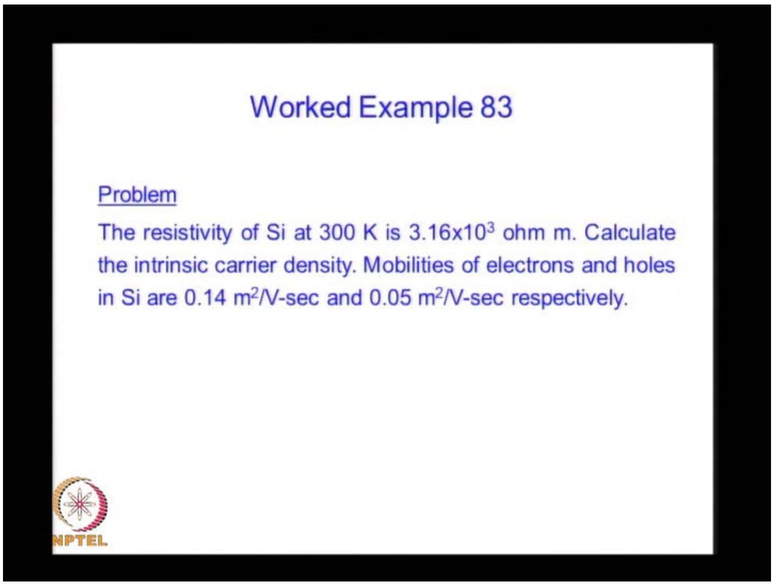

So, that is given as 0.14 metre square per volt second, and the mobility of holes.

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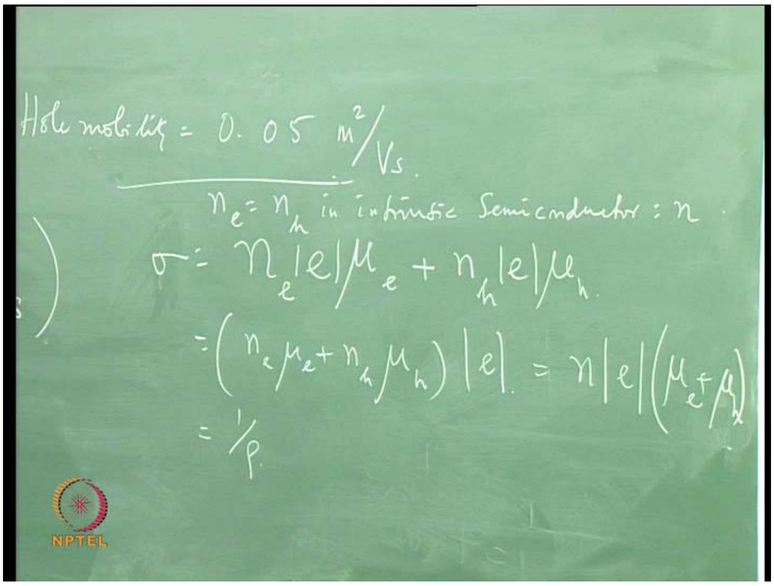

Is given as naught 5 point naught 5 and the current density is due to the presence of both electrons and holes in the silicon. So, there is a contribution from the motion of electrons among states in the conduction band, and also the motion of holes in states in the balance band both contribute to the current density. And since the hole is positively charged and moves in the direction opposite to that of the electron in the given electric field, therefore the current density is due to both electrons and holes add up.

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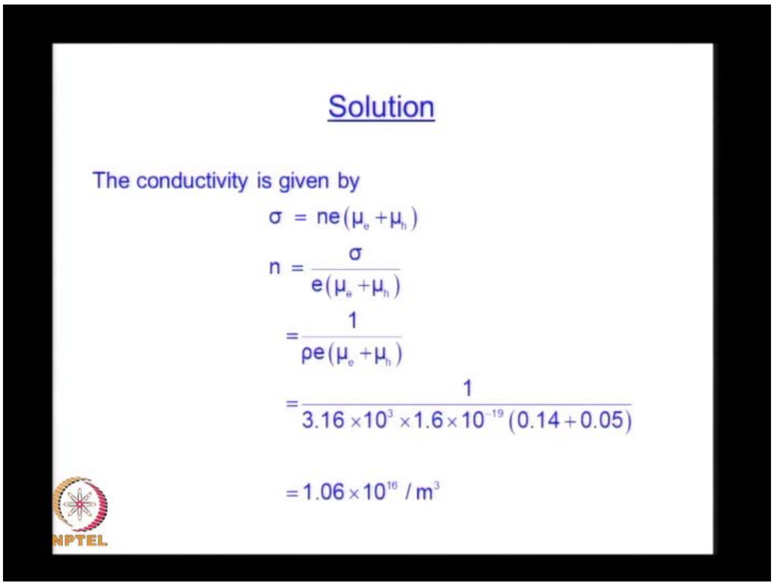

And therefore, we have a general relation using this using this fundamental relation. Now I can write n e e mu e plus n h e mu h where e is mod e the sign of the charge is included in the directions. Therefore, this is just n e mu e plus n h mu h times mod e and that is the general expression for j, and therefore sigma. And we also know that the resistivity rho is just one by sigma since it is a cubic material, we do not have to worry about anisotropic here sigma and rho are the same scalar quantities with just one value for the entire in all the directions inside the crystal. So, we are given the value the resistivity therefore, going back to this is equal to one by rho rho is given, and since it is intrinsic material the number of electrons is equal to the number of holes. So, let us write it together as n. So, that this becomes n e mu e plus mu h.

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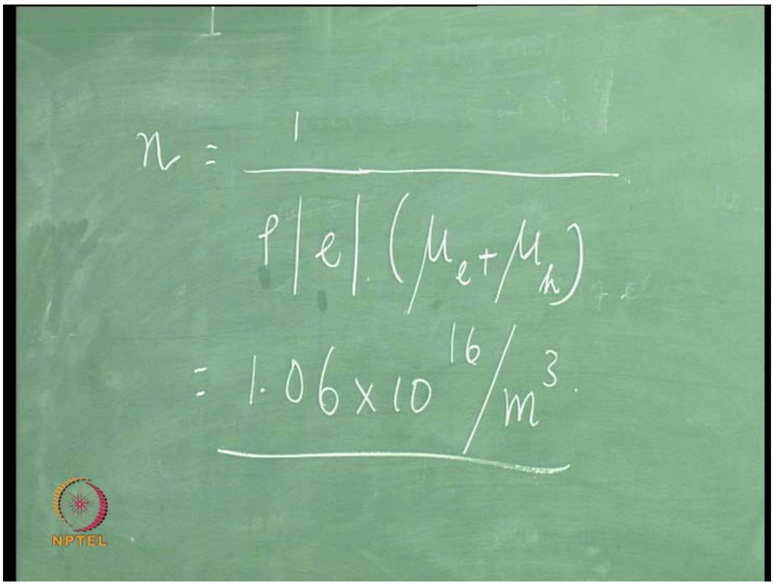

So, we have this and we are asked to determine n the intrinsic carrier concentration n, which is asked which is required is just given by one by rho times mod e noise times mu e plus mu h. So, plugging in the values the given values for the resistivity the electronic charge is known as standard value and the values of the mobilities are given substituting all these we get the value the carrier concentration is 1.06 into 10 to the power 16 per metre cube.

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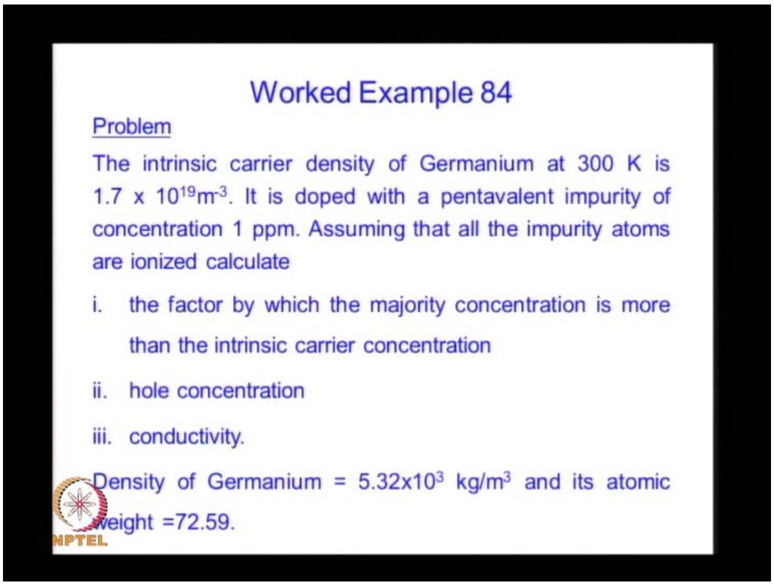

Next, we pass on to a case of intrinsic germanium .

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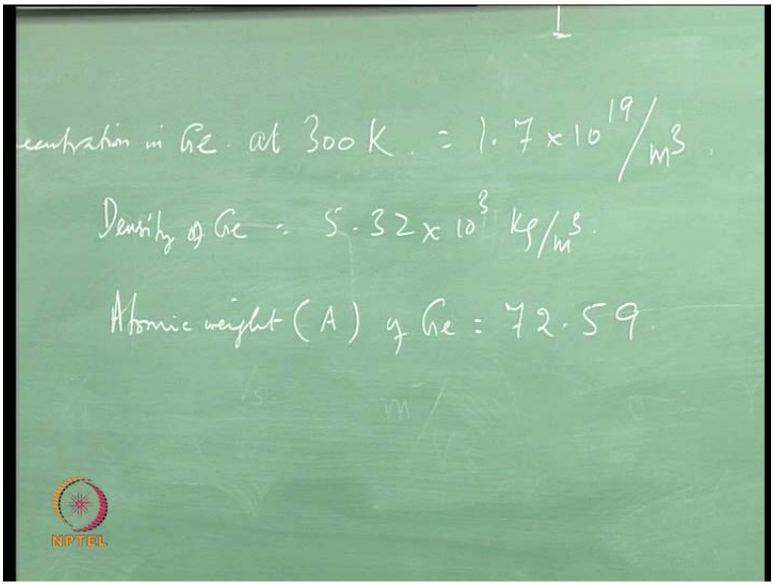

We are given the intrinsic carrier concentration in germanium at 300 k, and that is given as 1.7 into 10 to the power nineteen per metre cube. We are also given the value of the density bulk density of germanium as 5.32 into ten to the power three kilograms per metre cube, and the atomic weight of germanium is given as seventy 2.59 noise.

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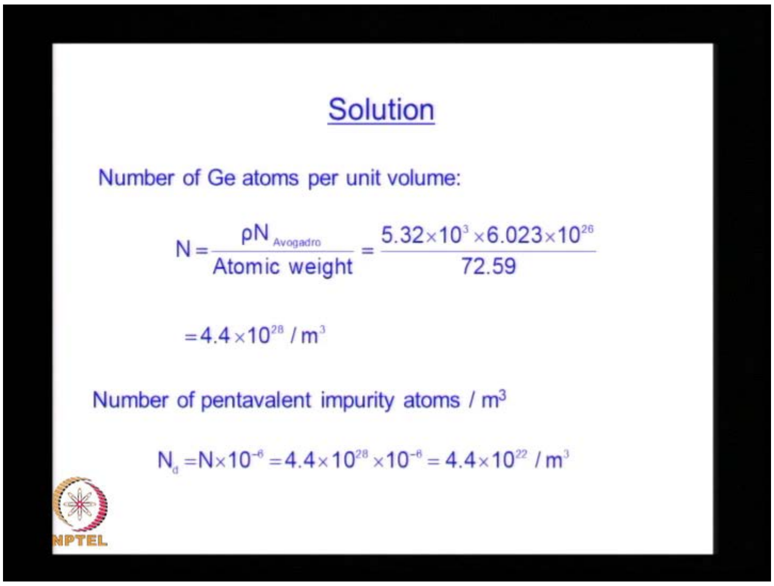

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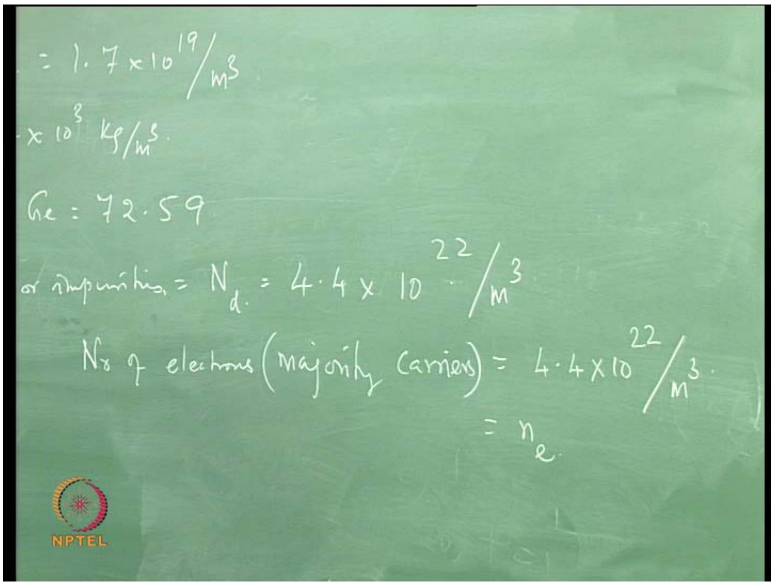

So, the number of germanium atoms per unit volume can be calculated using allocator number the density. And their atomic weight as 4.4 into 10 to the power twenty eight we are asked to assume; that the this germanium is doped with pentavalent impurity atoms at doped with and the doping concentration is one part per million which is ten to the power minus 6.

So, this is the number of germanium atoms and the number of impurities. These are donor impurities, they donate electrons the number of donors impurities is standard notation is n d and that is taking this number 4.4 into 10 to the power 28 and 10 to the power minus 6, and 10 to the power 22 per metre cube. And we assume that all of them are ionised all the impurities atoms are ionised. So, the number of electrons donated which are the majority carriers this the same number each impurity atom donates an electron. So, that is what we call usually n with a subscript e.

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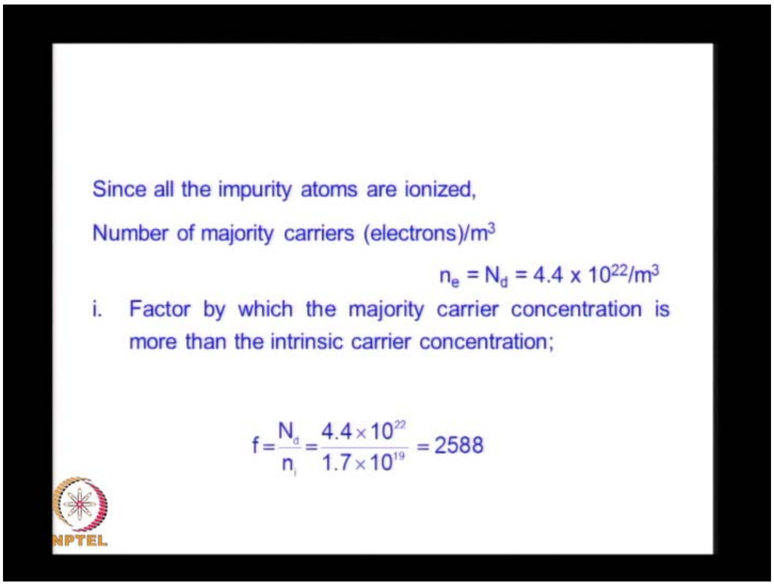

So, we were asked to calculate several quantities; for example the factor by which by what factor noise.

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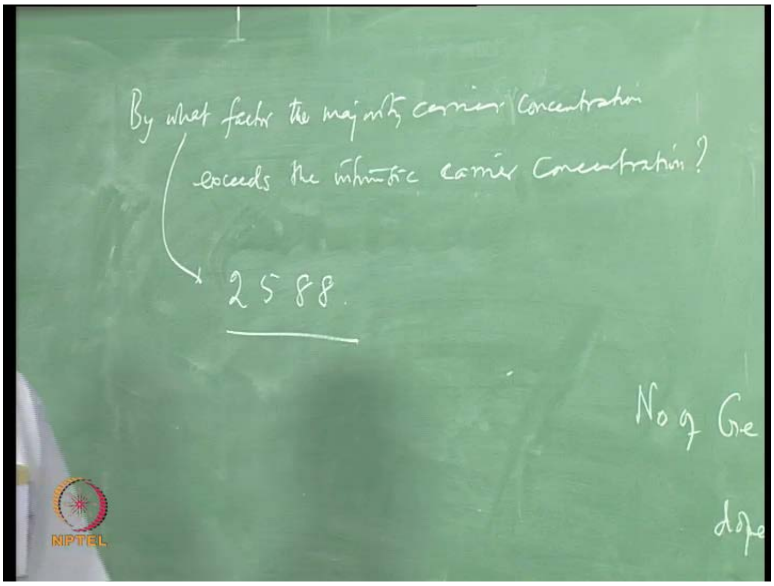

The majority carriers exceed carrier concentration exceeds the intrinsic carrier concentration. So, all we have to do is we are given the intrinsic carrier concentration, and we have determined the number of the majority carrier concentration namely that of electrons. So, we divide one by the other and get the factor as the answer is two thousand five hundred and eighty eight noise there are 2588 majority carriers for each intrinsic carrier. And since we know the number of this is what we know as n i intrinsic concentration.

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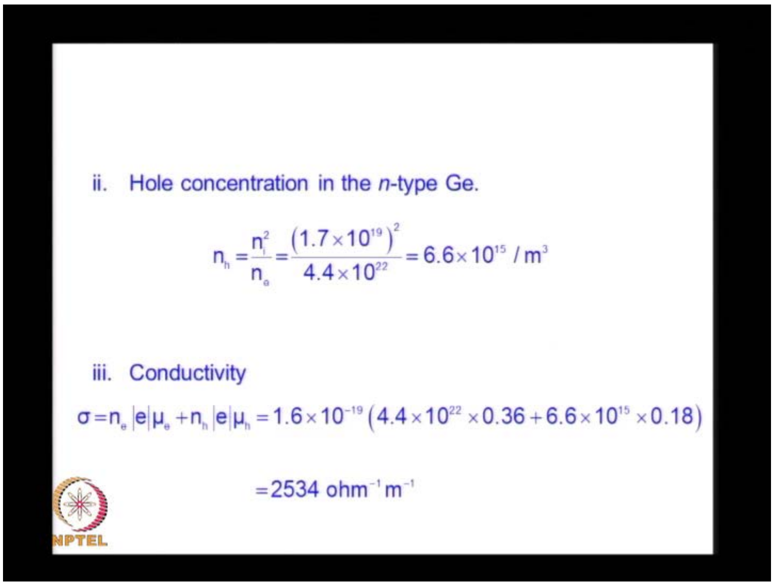

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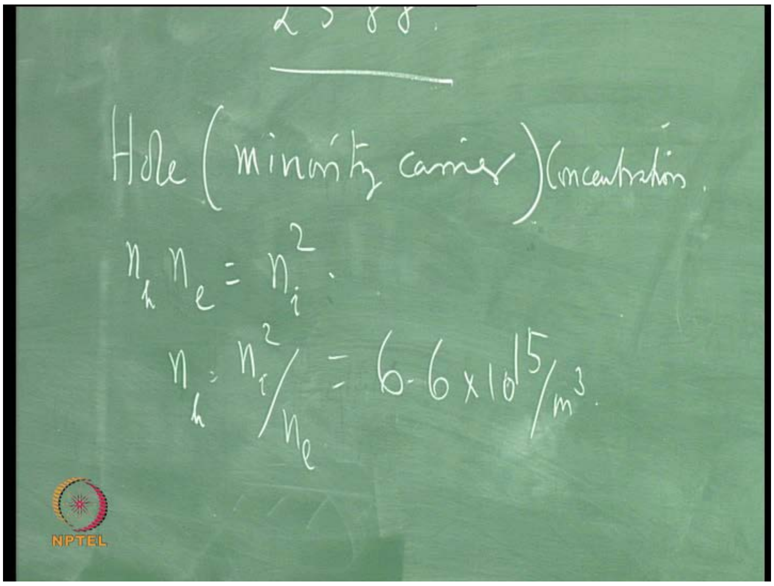

And therefore, the hole concentration hole, which is the minority carrier concentration is given by n h equals is such that n h times n e is n i square. So, we know n h is n i square by n e. So, substituting n i and n e we get the value of n h as 6.6 into 10 to the power fifteen per metre cube, because we know the majority and minority carrier concentrations. And we have been given the mobilities of the electrons, and holes we are now in a position to calculate the conductivity contributed by the electrons and holes.

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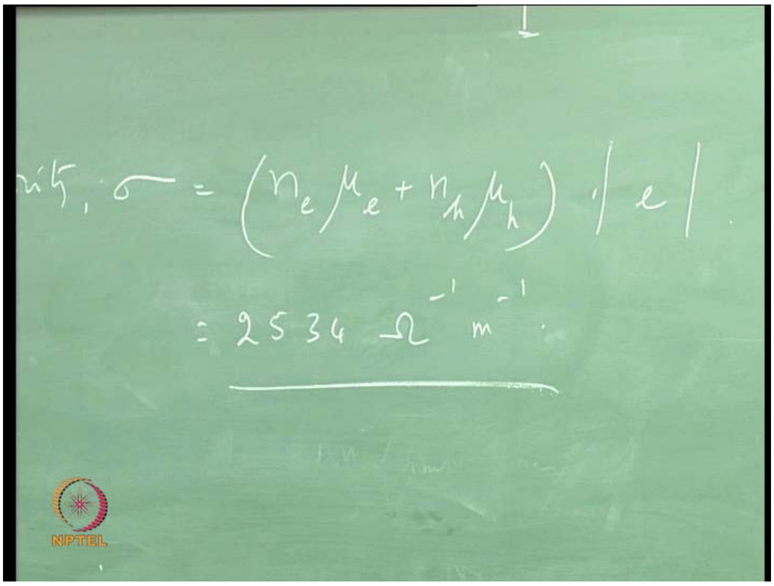

And hence the total conductivity noise sigma, which as we have seen n e mu e n h mu h times mod e. So, n e is known n h is known and therefore, we can calculate the conductivity and this turns out to be that is the value for the conductivity with the given mobility values.

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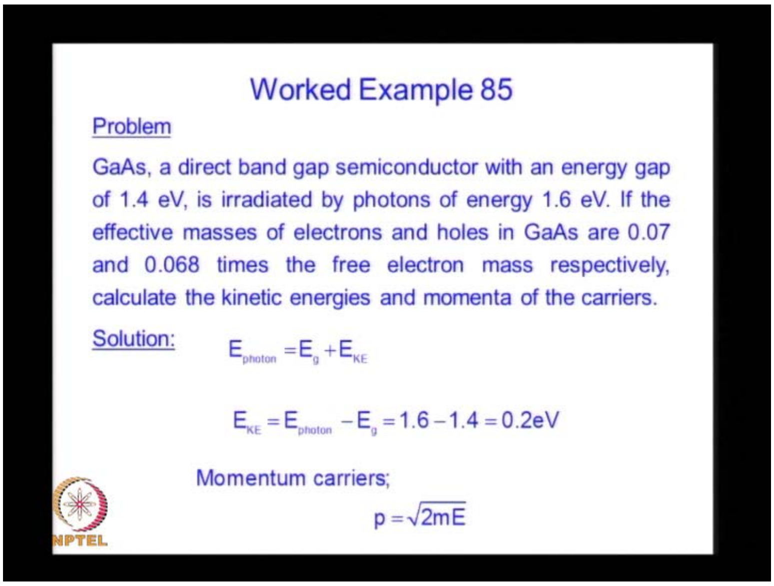

Next, we pass on to the case of gallium arsenide as we have already seen gallium arsenide is a compound semiconductor.

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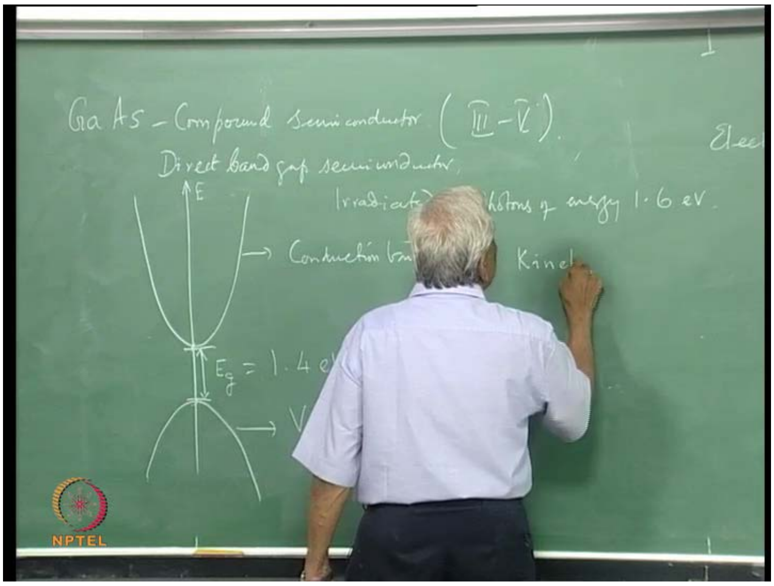

The gallium and arsenic gallium for the group three and arsenic from group five in the periodic table. So, it is a three to 535 compound. And we already saw in the lecture that it is a direct band gap semiconductor which means that the bottom of the conduction band and the top of the valence band lie exactly one above the other. So, these two are just above each other, and this difference in energy is the energy gap whose value is given in the case of gallium arsenide as 1.4 electron volts we are also told that this sample is evaluated with photons of energy 1.6 electron volts.

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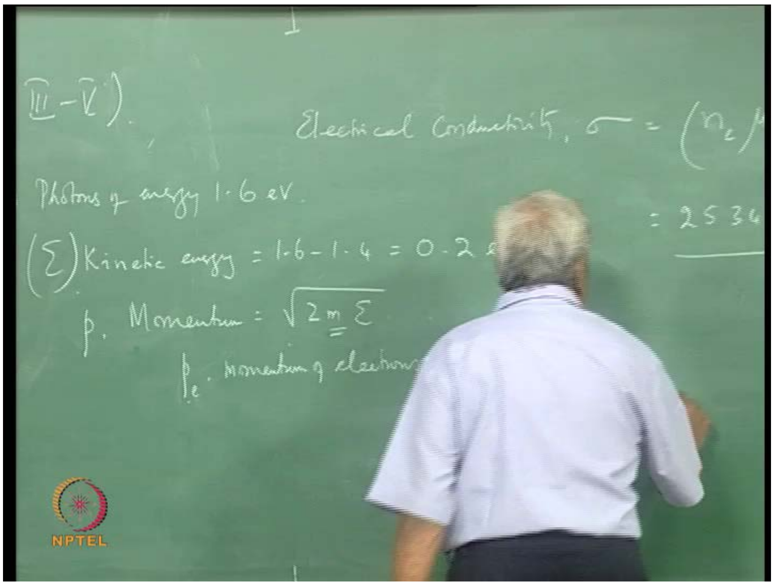

So, the difference in energy one point six and one point four gives you the kinetic energy of carriers that is the kinetic energy, and the carriers and since this is say e and therefore, the momentum is just root two m e p, therefore the momentum.

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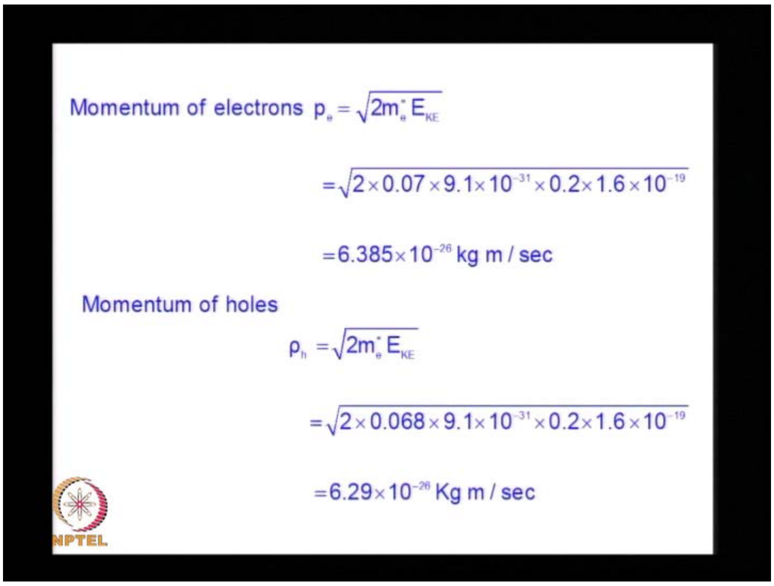

Of course in this case the mass is involved. So, the momentum will be different for the electrons and holes because the effective masses are different. So, the momentum of electron is root 2 m e star e. So, substituting the effective mass of electron which is given as point naught seven times that of the electron free electron therefore, substituting that they get at the momentum as 6.835 into 10 to the power of minus 26 momentum kilogram meters per second proceeding the same way.

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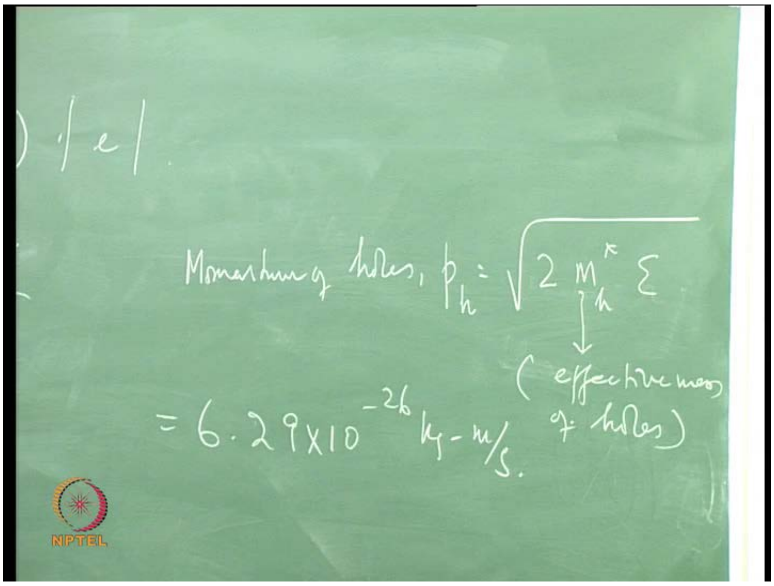

We get the momentum of holes two m h star e where this is effective mass of the... So, that is again given to be 0.68 times that of the free electron. So, substituting this value, we get the momentum as 6.29 into 10 to the power minus twenty six kilogram metre per second

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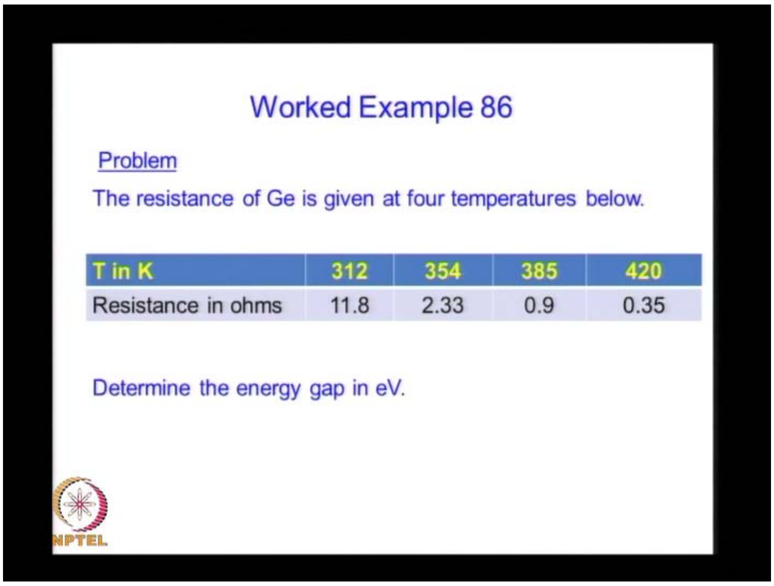

In the next problem, we are given data in the tabular form for the resistance of germanium.

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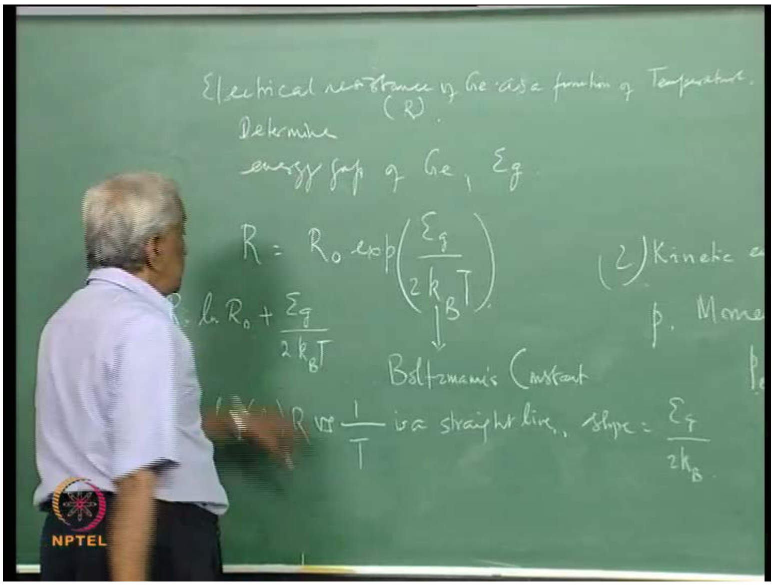

The electrical resistance of germanium is given as a function of temperature. So, we are given the values in ohm's of the resistance at 300, and 12 k, 354 k, 385 k, and 420 k.

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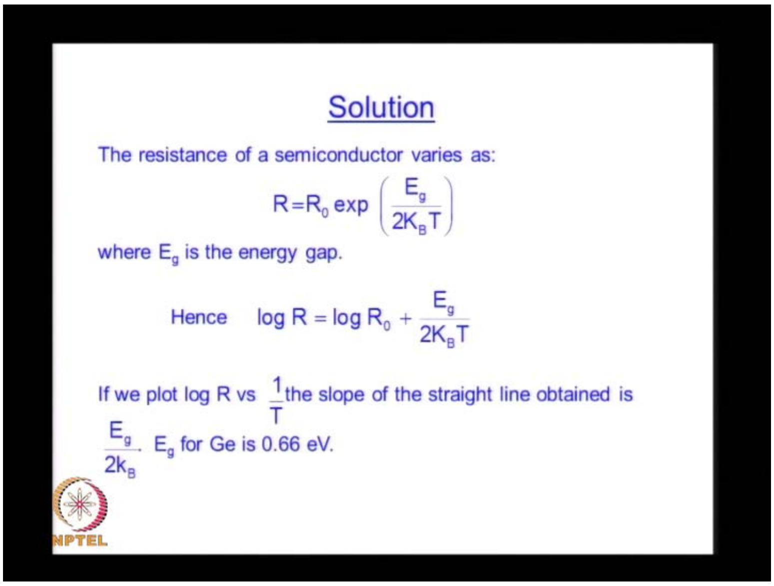

And we are asked to determine the energy gap at as a function of temperature resistance r. So, determine energy gap of germanium that is the question and for this. We know that the resistance as the temperature dependence, which has the form where e g is energy gap and kb is the Boltzmann's constant therefore, we take logarithms . So, a plot of log r r log also versus one by t is a straight line whose slope is e g by 2 k b. So, plotting this graph of log r versus 1 by t from the given values we get a straight line and the slope gives the energy gap in terms of twice the Boltzmann constant. And so we can determine the energy gap the energy gap turns out to be point six electron volts from the given data.

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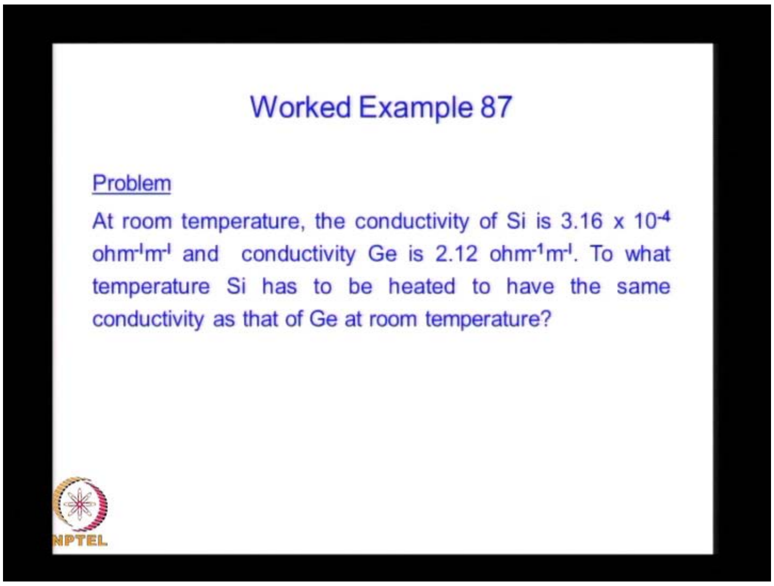

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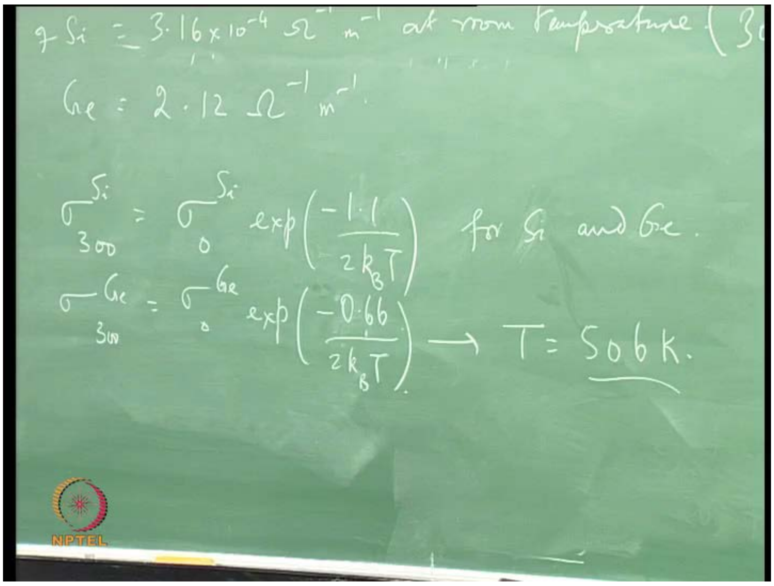

Next, question concerns the comparison of the conductivity of silicon conductivity means always electrical conductivity, in this case silicon is 3.16 into 10 to the power minus four at room temperature, and that of germanium is also given at room temperature as 2.12 ohm minus one metre minus one four orders higher.

So, we are asked to what temperature; obviously, if silicon is heated the conductivity increases if it has to have the same conductivity as germanium to what temperature should silicon be heated. So, that is the question. So, we have sigma three hundred we take this has three hundred k

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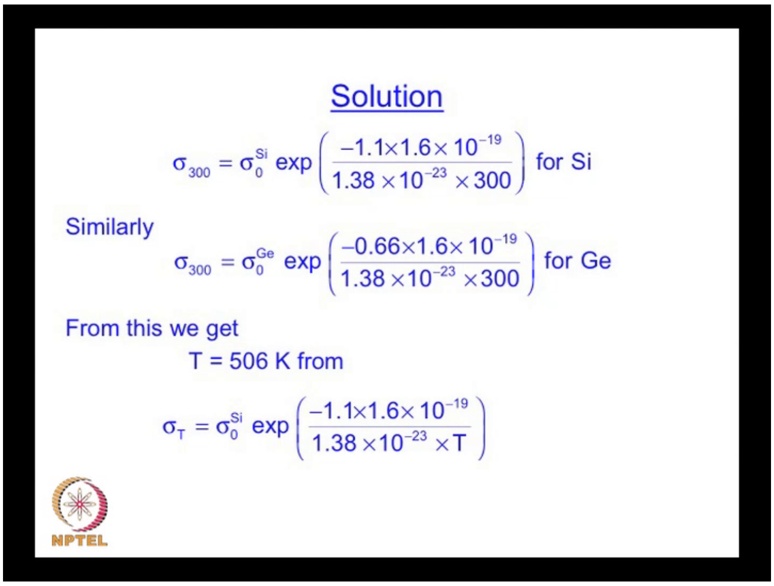

Is for sigma naught exponential minus e g by two kb t for both for silicon as well as Germanium. So, we can write it separately for the two of course, the energy gap values are different. So, the energy gap in this case is one point one electron volt and in this case it is 0.66 as we just know saw. So, we get using this eliminating sigma zero we get t s pi 06 kelvin. So, we have to heat silicon to 230 degrees celsius for it to get the same conductivity as germanium at room temperature.

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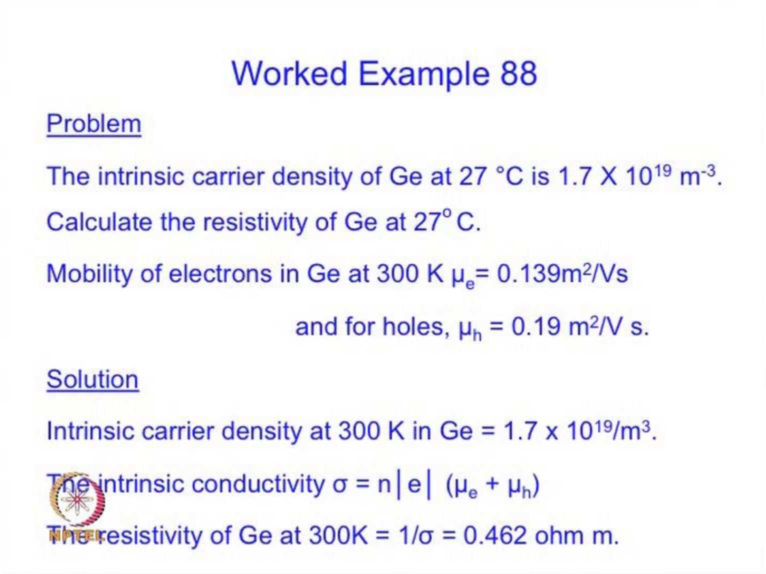

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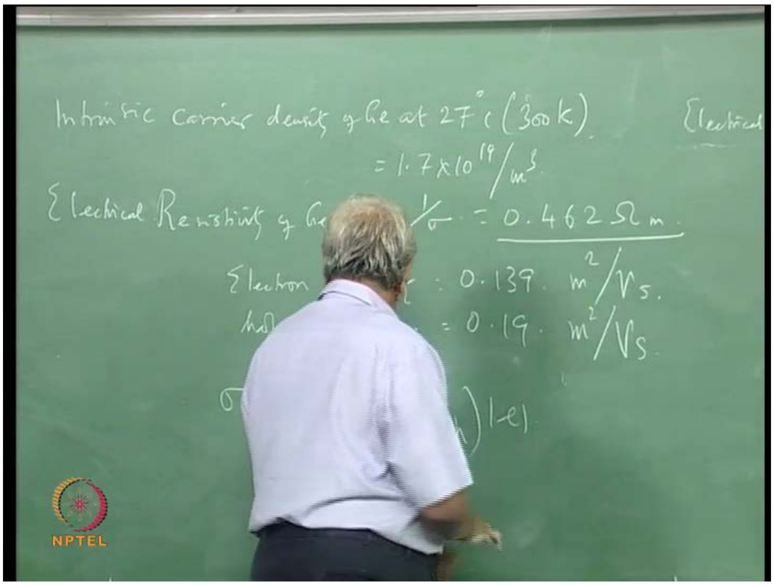

Next, we are given the intrinsic carrier density of germanium as 1.7 at 27celsius, which is the same as 300 k as 1.7 into ten to the power 19 per metre cube. So, we are asked to calculate the resistivity of course, electrical resistivity we have given electron and hole mobilities for germanium they are given at this temperature as point one three nine ten point one nine metre square per volt second. Therefore, with this we can write the usual conductivity formula where of course n e and n h are the same, therefore we need even write this like this where n is the common concentration.

So, the resistivity is one by sigma. So, this is one by sigma, and therefore we can calculate from these substituting finding sigma from here and then taking the reciprocal we get the value as naught 0.452 ohm metre, which is the answer we have done given a problem on silicon

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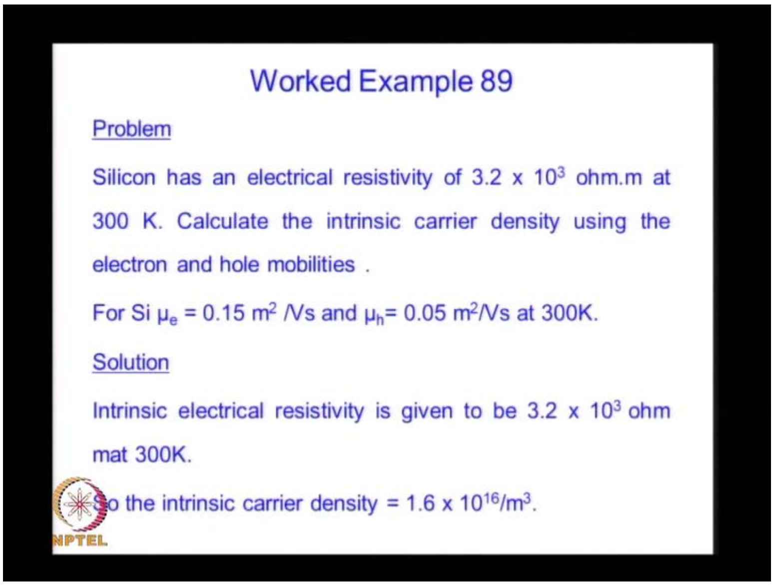

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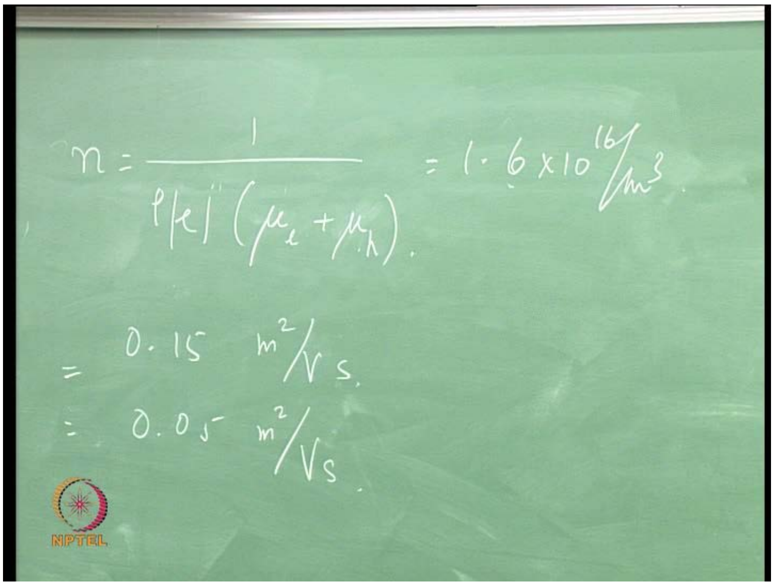

Here it is the inverse problem the resistivity is given no it was three resistivity at three hundred k. So, we are asked to calculate intrinsic carrier density with the data on electron and hole mobility in silicon. So, this is given as point one five and point zero five metre square per volt second. So, this is mu e this is mu h noise. So, we have to calculate the intrinsic current density which is straightaway given by and... So, substituting all this values we get one point six into ten to the power 16.

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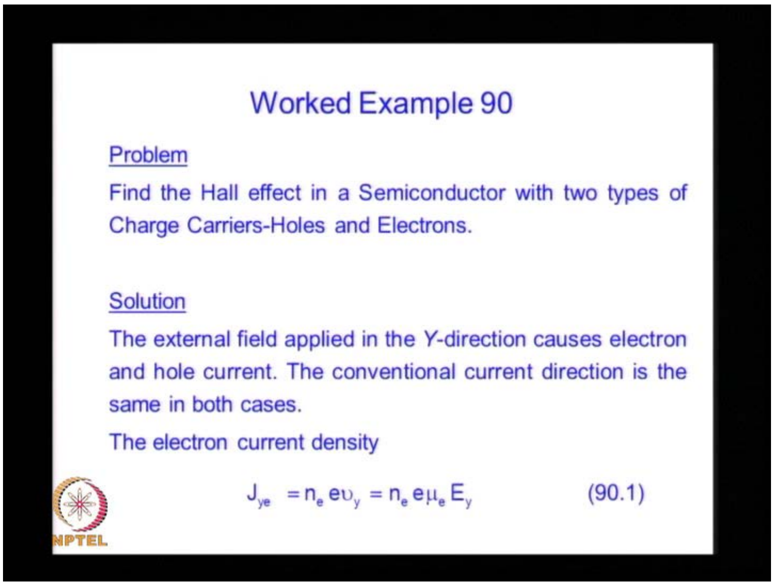

The last question concerns the hall effect in a semiconductor with two types of carriers the electrons and holes.

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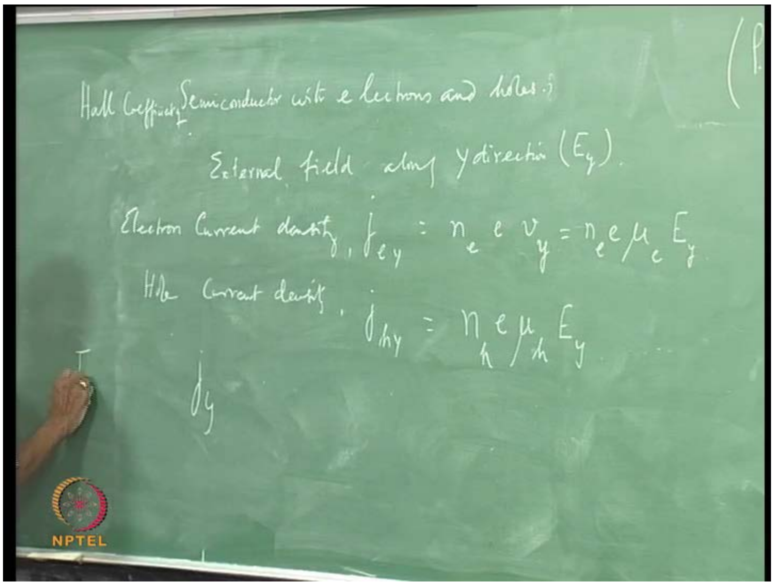

So, we discussed in the lecture the hall effect for a semiconductor with one type of carriers now hall coefficient. So, that is what we are asked to determine. So, suppose we have an external field, hall effect is an effect which is produced then there is an external field applied at right angles to the direction of motion of the carrier in a current carrying semiconductor. So, external field is taken along y. So, let us call it e y. So, the electron current density will be will be j e y, which will be carrier concentration electron concentration times the electron charge times the speed of the electron along the y direction. And this in terms as the mobility, it is mu e mobility as electron times the field e y similarly for the hole current density h y that would be by the same token it will be n h e mu h e y. And therefore, the total current as we already discussed the holes will move in the direction opposite to that of the electrons they will move along the electric field direction. And these electrons will move opposite to the electric field direction, but since they are of opposite charges the current densities will be added. So, this will be n e mu e plus n h mu h times e e y now because of this current.

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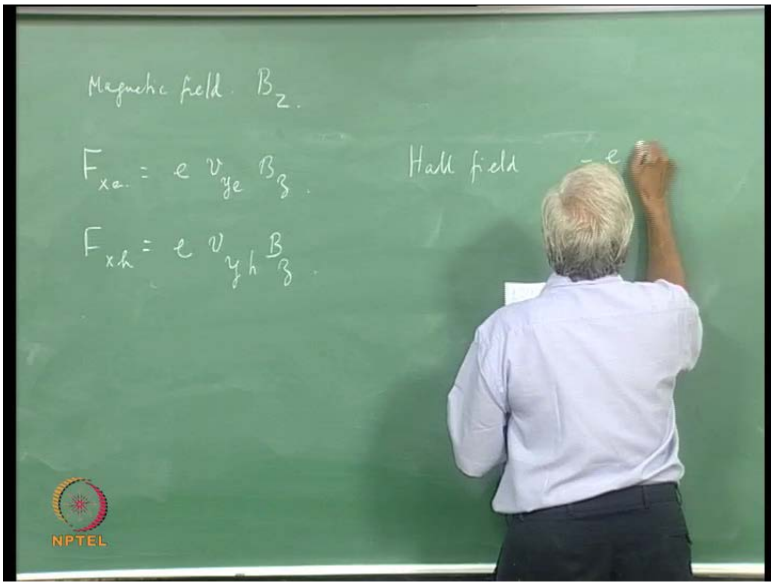

And because of the magnetic field is taken it should be at right angles the electric field y direction as well as the initial current density. So, we take it along the z direction. So, the force the Lawrence force on the electron which will be in the direction perpendicular to y and z namely x direction. So, we write it as f x e will be e v ye b z the force acting on the hole is e v y h b z.

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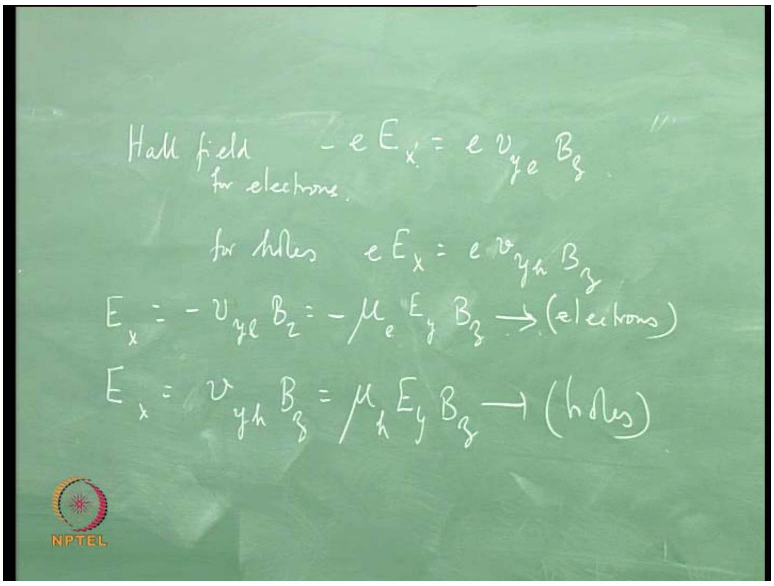

So, the hall field because of the lateral moment of the electrons and holes there will be a hall fields which in the case of the electrons it is directed along the x direction. Therefore this is e v y e b z, and for electrons due to motion of electrons in the x direction and for holes similarly it will be e ex equals e v y h b z noise. Therefore, ex in these two cases will be minus v ye b z, which in terms of the mobility it is mu e times e y b z and for this is for the electrons. And similarly ex will be e v y h b z which in terms of the mobility is mu h e y b z this is for the holes. So, since there is a hall field in the lateral direction given by the sum of these two there will be a current density the motion of carriers.

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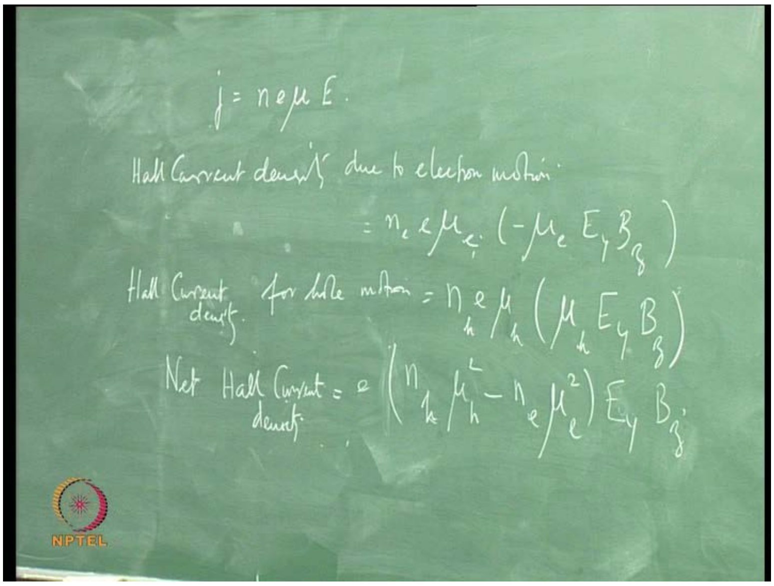

And there will be a current density contributed from both which is given by the standard relation n e mu e. Therefore, the hall current densities due to electrons electron motion and that will be n e e mu e using this times that electric field. So, that will be minus mu e e y b z and for the holes. Similarly for hole motion this will be n h e mu h into mu h e y b z noise. So, the total current a net hall current will be e times n h taking these two n h mu h square minus ne mu e square times e y b z. So, this will be the hall current density.

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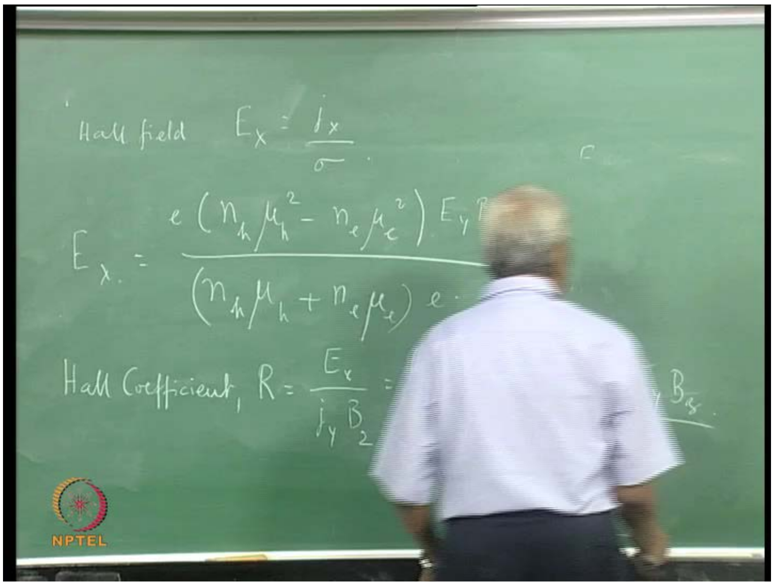

So, this hall current density will be result in a hall field due to this current density and that is e x is j x by sigma by ohm's law again therefore, this will be e times borrowing this expression n h mu h square minus n e mu e square into e y b z by the conductivity which is n h mu h plus n e mu e times e noise. So, and the hall coefficient r is just ex by j y b z and that will be borrowing, this expression n h mu h square minus n e mu e square times e y b z by n h mu h plus n e mu e here times j y b z, and this is nothing but sigma e y b z. So, this will give me simplifying substituting for sigma again that will be the hall coefficient in a semiconductor containing two carriers. And it is a simple matter to go from here, and show that this will lead to the standard expression r equal to one by n e in the case of a semiconductor with just one type of carriers.