# Materials and Energy Balance in Metallurgical Processes

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## Exercises on Measurement of Quantities Introduction to Stoichiometry

This lecture is in continuation of the previous lecture on measurement of quantities. I will proceed here further.

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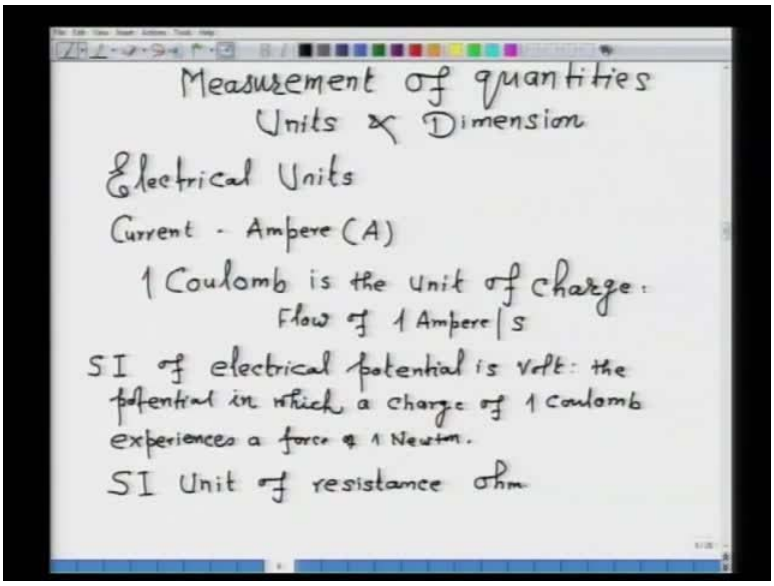


So, next comes electrical units. Current, as all of you know, is usually measured in ampere; and in short it is denoted by A. In solids, the flow of current consists of flow of electrons.

In electrolytic solutions, most of the current flows by movement of ionic species.

Now 1 coulomb is the unit of charge; and that is flow of 1 ampere in a second; that is what 1 coulomb is.

Now, SI unit of electrical potential is volt. I think all of you know. Volt is the potential in which a charge of 1 coulomb experiences a force of 1 Newton.

Now, this is about the volt. Now, as you know, SI unit of resistance, do you know what the SI unit of resistance is? It is ohm.

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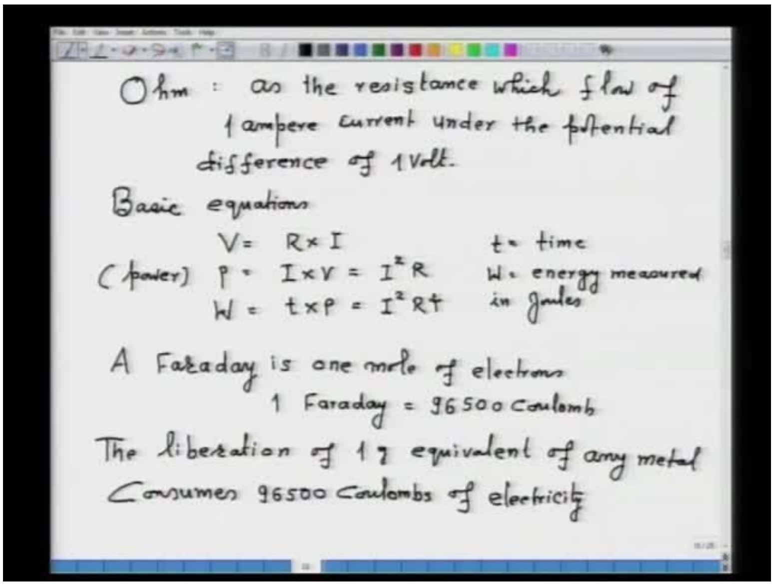


Now, it is basic and elementary, I am just reviving; ohm is defined as the resistance which permits flow of 1 ampere current under the potential difference of 1 volt; that is how we define the ohm.

Now, some basic equations for electrical flow are: that is volt, as all of you know; that is equal to resistance into current, that is I.

Now P is power; that is equal to I into V; that is also equal to I square into R; and W, that is the energy, which is measured in joules; that is t into P; that is equal to I square R into t. Now here t is equal to time; W - energy measured in joules; and P is the power. Now another important unit is a faraday. A faraday is 1 mole of electrons. 1 faraday is equal to 96500 coulomb.

Now it should also be known that 1 faraday, on passing in an electrolyte will discharge 1 gram equivalent of ions. The liberation the liberation of 1 gram equivalent of any metal consumes 96500 coulombs of electricity. These are some of the basic units and dimensions for electric flow.

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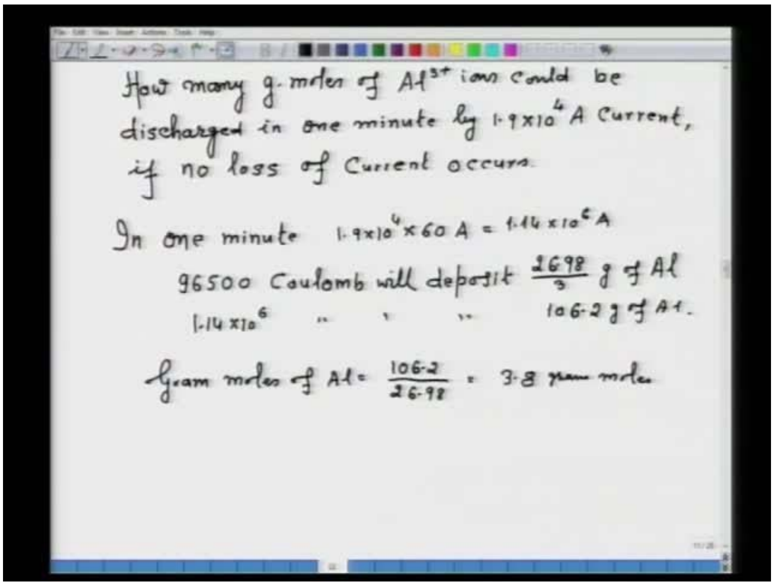


Now, let us consider, say, how many gram moles of Al 3 plus; you know Al, aluminum at 3 charges ions; could be discharged in 1 minute by 1.9 into 10 to the power 4 ampere current, if no loss of current occurs.

It's a very simple problem; that means if you pass 1.9 into 10 to the power 4 ampere of current in the electrolyte, in order to discharge Al 3 plus to aluminum, how many gram moles of aluminum will be deposited? Very simple.

So now, let us calculate say, in 1 minute, how much current will flow? 1.9 into 10 to the power 4 into 60 coulomb; that much current will flow.

Now, you know 96500 say coulombs will deposit; the molecular weight of aluminum is 26.98; 26.98 divide by 3 gram of aluminum. That is what the definition of this is. Therefore, this will be coming approximately equal to 1.14 into 10 to the power 6 coulomb. That means, we can straightaway say this; 1.14 into 10 to the power 6 coulomb will deposit around 106.2 two gram of aluminum; and gram moles of aluminum would be 106.2 divide by 26.98; and that will be equal to 3.8 gram mole; this is a very simple question.

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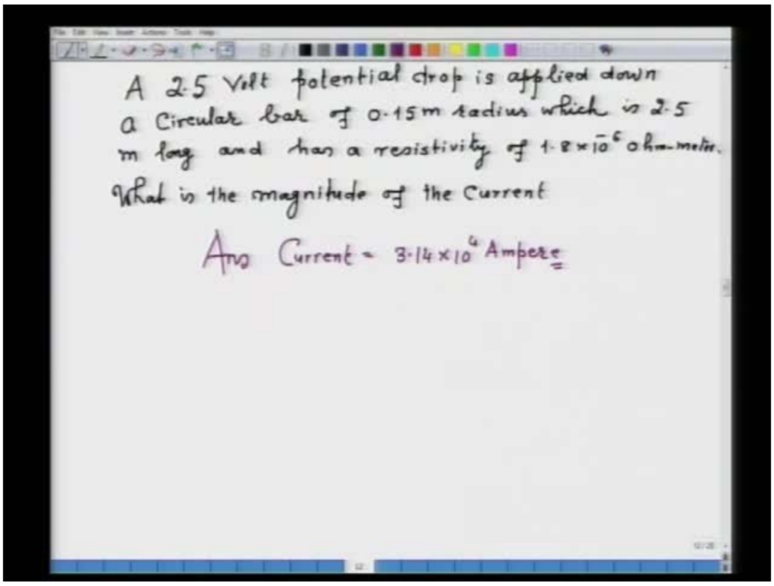


Let me give you another problem, for example, if you consider; again very simple problem; a 2.5 volt potential drop is applied down a circular bar of 0.15 meter radius which is 2.5 meter long and has a resistivity of 1.8 into 10 to the power minus 6 ohm.

What is the magnitude of the current?

Now I will request you to solve this problem on your own; all that you have to calculate is the area of the bar and find out the resistance; and then find out current.

Answer for this problem is: Current comes out to be equal to 3.14 into 10 to the power 4 amperes. Try yourself and get a feel of the calculations on electricity.

Now with this, I finish the conceptual part of the lecture on measurement of quantities.

Now, I will try to give you exercise with some solved problems and some unsolved problems.

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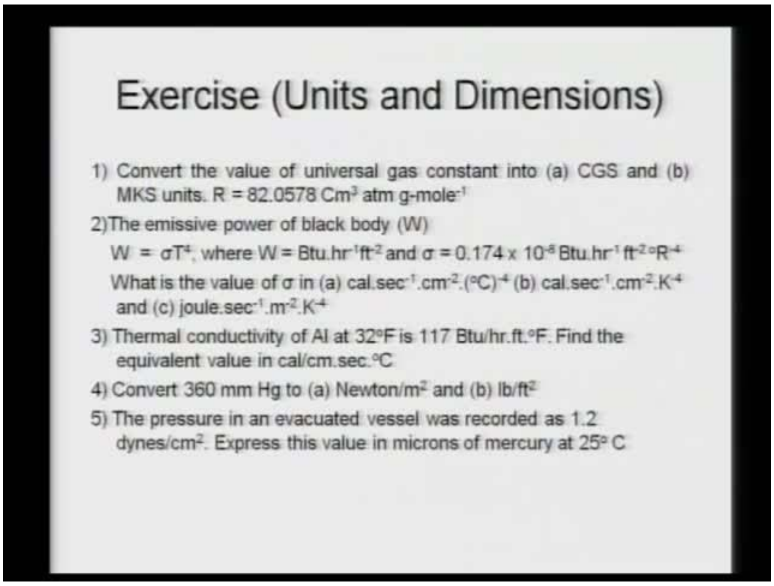


Now, let us see the exercises; these are the exercise on units and dimension. I will read, first of all, all the problems; and then I will solve or I will give the answers one by one, as I proceed.

Problem 1: convert the value of universal gas constant into (a) CGS and (b) MKS units; given R is equal to 82.0578 centimeter cube atmosphere gram mole to the power minus 1.

So, what is involved in this problem? In fact, you can see the value of R in CGS and MKS unit in any standard book and you can straightaway write down the answer, but that is not the objective of this particular problem.

What I would like is that from given the dimension of R - centimeter cube atmosphere gram mole to the power minus 1, you should be able to derive by suitable multiplying factor, on your own, the unit of R in CGS and MKS system.

That is the intention of this particular problem. I know that several books give the value of R in different dimensions; you can see and you can write, but that will not serve the objective of giving this particular problem; you have to derive the units from fundamental units; that is mass length, time and temperature. That is the intention.

Problem 2: The emissive power of a black body is sigma T to the power 4; where W is Btu per hour per feet square, is given; and sigma is given to you, in this unit.

So what is the value of sigma in (a) calorie per second per centimeter square degree Celsius to the power minus 4? (b) in calorie per second per centimeter square Kelvin to the power 4? and (c) joule per second per meter square Kelvin to the power 4.

Again you have to derive this unit from the basic units, because as I said in my last lecture, all the units can be derived from the fundamental units; that is the thing.

Third, thermal conductivity of aluminum at 32 degree Fahrenheit is 117 Btu per hour feet degree Fahrenheit; find the equivalent value in calorie per centimeter per second degree Celsius.

Now, here again, you can straightaway see the book; multiply by the conversion factor; and you will get the value. But that is not the objective of this particular exercise. The objective of this particular exercise is that you find out by suitable factors, the units in calorie per centimeter per second degree Celsius.

Convert 360 millimeter mercury to Newton per meter square and pound per feet square.

Fifth, the pressure in an evacuated vessel was recorded as 1.2 dynes per centimeter square; express this value in microns of mercury at 25 degree Celsius.

Now, you must have noted here that I tried to give problems in all the 4 basic system, hat is CGS, MKS and FPS. All that you must understand is with the inter conversion of units from one system to another system; that is the important thing.

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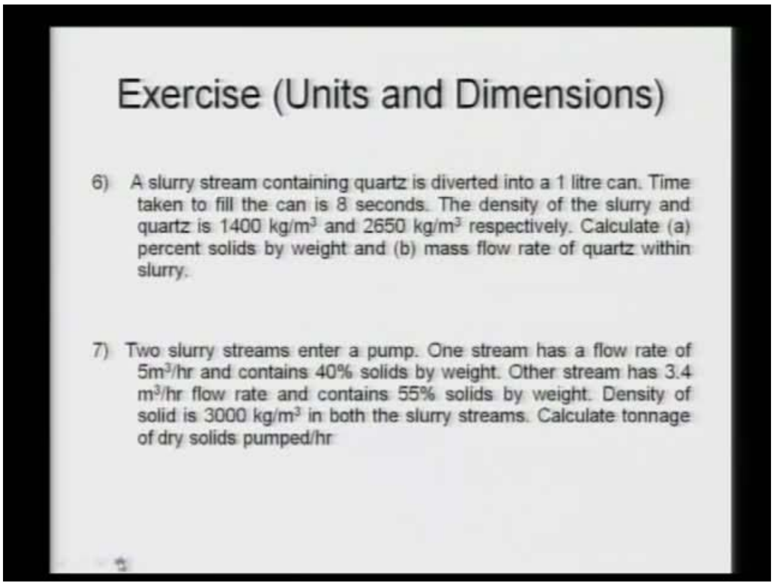


Now, problem number 6, a slurry stream containing quartz is diverted into a 1 litre can; that is, a slurry is flowing; you have taken a 1 litre can; and into this you have diverted that slurry.

Time taken to fill the can is 8 seconds; the density of the slurry and quartz is 1400 kilogram per meter cube and 2650 kilogram per meter cube, respectively.

Calculate (a) percent solid by weight and (b) flow rate of quartz within the slurry. So this problem is very important when you proceed to the material balance in metal extraction and refining.

Problem 7: 2 slurry streams enter a pump; There is a pump and 2 slurry streams enter into it. 1 is stream has a flow rate of 5 meter cube per hour and contains 40 percent solids, by weight.

Other stream has 3.4 meter cube per hour flow rate and contains 55 percent solids, by weight. Density of solid is 3000 kilogram per meter cube, in both the slurry streams. Calculate tonnage of dry solids pumped per hour.

So, these are the problems that are given to you for the exercises. Now, I will discuss one by one and where I will see that I should give the solution, there I will give, otherwise I will give the answer and proceed to the next.

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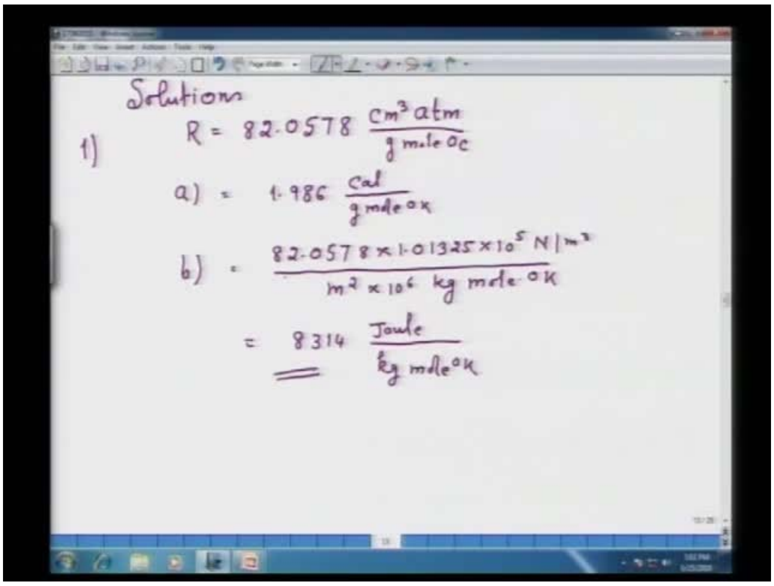


So, let us take the solutions of the exercise; see number 1 - the conversion of units, what I meant, for example, you have to convert in CGS units; so you are given R, that is given to you - 82.0578; and it was given in centimeter cube atmosphere gram mole degree Celsius.

Now we have to obtain in CGS unit; so all that you have to do is, you have to inter convert it; and I will straightaway giving the answer; the answer will be 1.986 calorie per gram mole degree Kelvin; that is the answer for part (a).

Now similarly, for part (b) you have to derive in joule per kg mole degree Kelvin and you can see that is given 82.0578 into pressure - 1.01325 into 10 to the power 5; that is in Newton per meter cube; and if we divide here say meter square into 10 to the power 6; i am just deriving from here, so that is why this thing is coming; into 10 to the power 6 kg mole and degree Kelvin, is already existing there.

So that is equal to 8314 joule per kg mole degree Kelvin and that is the answer for (b).

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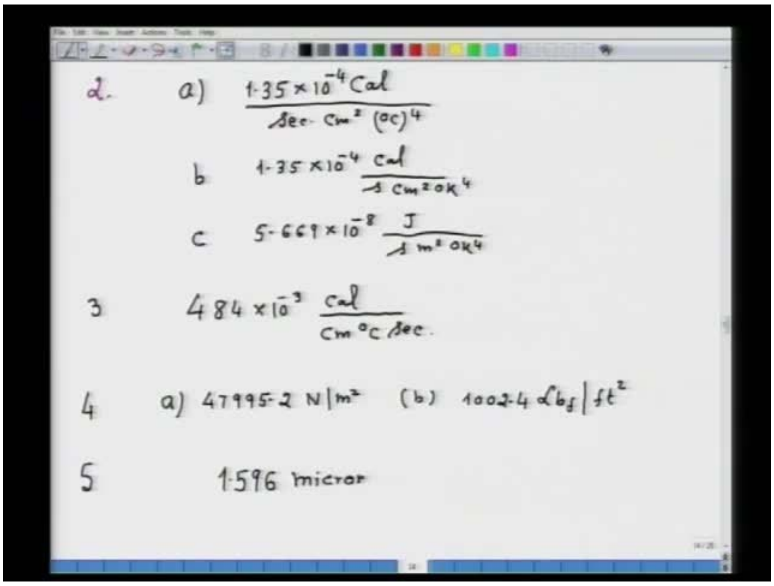


So now, let us proceed to the problem number 2; the problem number 2: the emissive power of a black body; so I am giving you the answer; you try to derive the answer for part (a) that is equal to 1.35 into 10 to the power minus 4 calorie per second centimeter square degree Celsius to the power 4.

Answer for (b) that is also 1.35 into 10 to the power minus 4 calorie per second centimeter square degree Kelvin to the power 4.

Now, the answer for (c) 5.669 into 10 to the power minus 8 joule second meter square degree Kelvin to the power 4; so, that is what is the answer for question number 2.

The answer for question number 3; you have to convert thermal conductivity; and the answer is 484 into 10 to the power minus 3 calorie per centimeter degree Celsius per second.

Now answer for question number 4, you have to convert, you can a straightaway try; I will give you the answer (a) part is 47995.2 Newton per meter square; and for (b), the answer is 1002.4 pound force per feet square.

The answer for 5 th, where you are require to convert 1.2 dynes per centimeter square into microns of mercury; so the answer is 1.596 microns.

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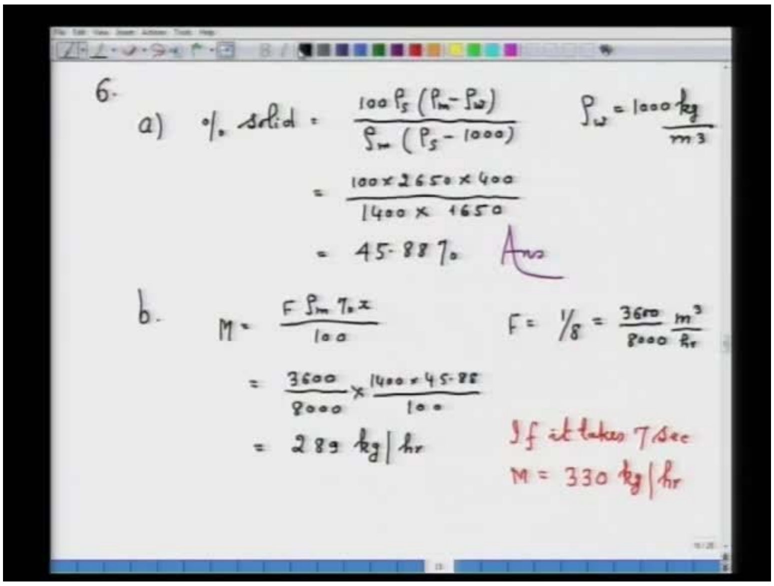

Now let us try question number 6; now question number 6 says a slurry stream containing quartz is diverted into 1 litre can; and it takes 8 seconds to fill the can; the density of the quartz and that of slurry are given, you have to calculate percent solid by weight. If you recall, in my first lecture, I derived how to calculate weight percent solid.

So straightaway, I will be using this formula and I will solve this particular problem for you; so for (a) part, percent solid; you recall, I am writing the formula again; that is equal to 100 rho slurry, $\rho_m$ minus $\rho_w$ divided by $\rho_m$ $\rho_s$ minus 1000, where $\rho_s$ is the density of the solid rho m is the density of the slurry this already i have given so what i'll do i will straightaway substitute the value.

So 100 into 2650 into 400; so density of water, as you have to take around 1000 kilogram per meter cube; so that divided by 1400 into 1650.

So that straightaway gives you the answer 45.88 percent; that is the answer for the part (a).

Now the part (b); it ask you mass flow rate of quartz within the slurry; because this slurry is required to be transported by pump from one place to another.

So you have to know what the mass flow rate of quartz is, because quartz is most important.

So, we have derived the formula; mass flow rate, M - that was, if you recall, F into $\rho_m$ into percent x upon hundred. So all that I have to substitute is the value and I have to get the answer.

So, if I substitute all these values, because you know F is the mass flow rate; that is 1 upon 8; 1 litre it takes around 8 seconds.

So if I convert in the units, then it will come around 3600 upon 8000; that will be in meter cube per hour.

Now, all that I have to do is substitute the value; so that will be equal to F is 3600; divided by 8000; density of the slurry is 1400; and percent x, that we have calculated - 45.88; of course, divided by the 100.

So this mass flow rate of the slurry comes to be equal to 289 kilogram per hour.

Now, for example, f it takes 7 seconds to fill up the 1 liter can, then mass flow rate of the slurry, naturally, will be 330 kg per hour; a just a side problem that I thought I will give you.

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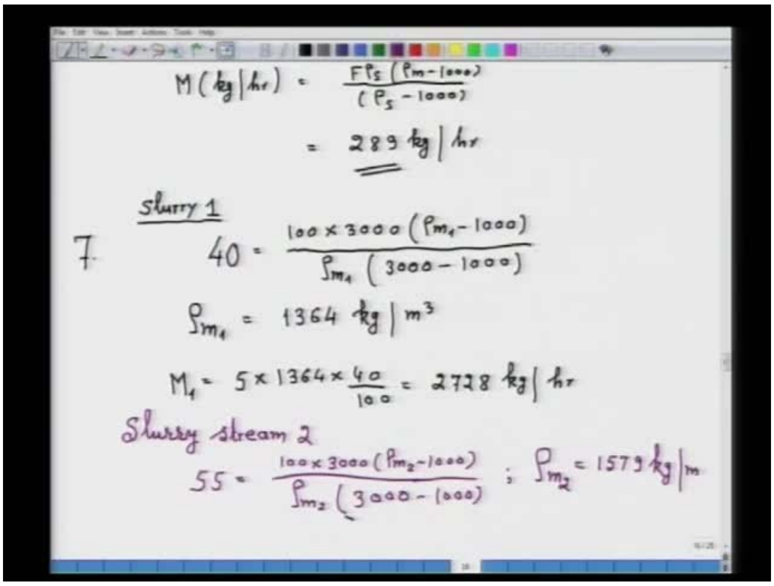


Now the same M, you know, we also derived an alternative formula; that is M in kg per hour; in case, you do not want to calculate percent x; then straightaway, you can use it.

That will be equal to F into $rho_s$ $rho_m$ minus 1000 upon $rho_s$ minus 1000; you calculate, you will be getting the answer again as 289 kilogram per hour.

That means, here, this problem was solved sequentially; that is, first, you calculate percent x; and then calculate kilogram per hour.

Now, yet, you are not required to calculate weight percent solid; straightaway, it has been ask that calculate the mass flow rate of the quartz in the slurry; then you have to use this particular formula; all that you have to do is replace the percent solid in terms of the quantities, which are given to you; that is the only difference.

So that is an alternative way or which every way you want to think.

Now, the last problem of this particular thing, that is the seventh problem; its again a very interesting problem. Many a time 2 different flow rates are required to be transported. The 2 different flow rates, they may have different densities and different percentage of solid; both of them pass to a pump and then the pump discharges a single stream.

So, this problem is that 2 slurry streams enter a pump; and the flow rate of both of these streams are given; percentage solid is given, as well.

So, now you have to calculate tonnage of dry solids pumped per hour; now, this particular problem has a significance because in all mineral processing operations, you are required to handle the slurries.

Slurry means a solution of solid in water; a large amount of solids in water are being handled for concentrating operations

So many times, you are required to designate what is the capacity of the pump you require; for that, you must know how much amount of solid will be transported per hour and that particular problem is addressed to that particular issue.

So here, well, I will proceed in my style; but I will request all of you to please do it yourself; develop a new method of solution.

What I will be solving, I will be, first of all, calculate the density of slurry in both the streams and I will proceed that way.

So I have given the formula already, for the interconnection between weight percent solid and the densities; that is already known to you.

So, I am a straightaway substituting those value; so in 1 slurry, you have 40 percent; 40 is equal to 100 into 3000 into $rho_{m1}$, that is density of slurry 1 minus 1000; divide by $rho_{m1}$ into 3000 minus 1000. So this way I can calculate now the value of $rho_{m1}$, density, that is equal to 1364 kilogram per meter cube; this is for slurry 1.

Now, here itself I can calculate the mass flow rate of slurry stream 1, that is, M1; that is equal to 5; all the values are given; into 1364 into 40 by 100; and that is equal 2728 kilogram per hour; this is the mass flow rate of slurry stream number 1.

Now, let me calculate for slurry stream number 2; I will proceed the same way and calculate the density of slurry 2.

So, 55 percent solid; that is given; 100 into 3000 $rho_{m2}$ minus 1000 upon $rho_{m2}$ 3000 minus 1000.

If I solve for $rho_{m2}$ from here I will be getting density of slurry stream 2; that is equal to 1579 kilogram per meter cube.

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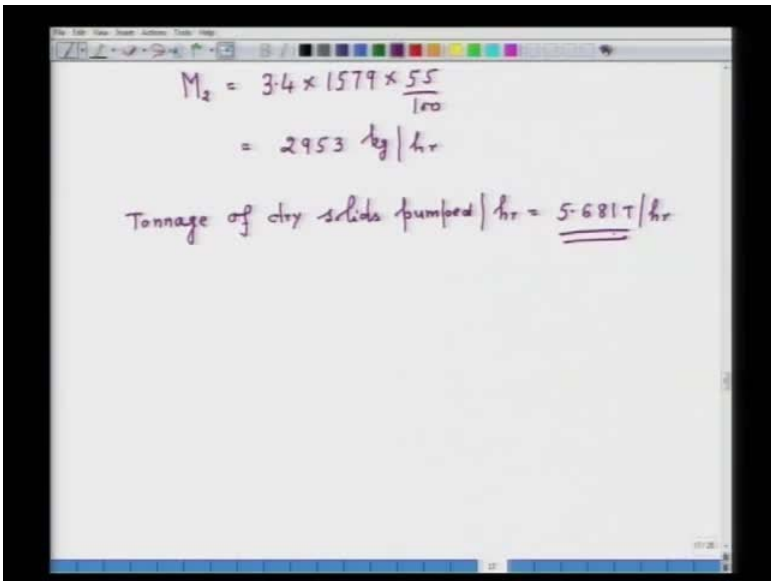


So I can calculate now mass flow rate, that is, $M_2$. The flow rate is given, 3.4 into 1579 into 55 by 100; so that will be equal to 2953 kilogram per hour.

So tonnage of dry solids pumped per hour will be; I have to sum total both of them; 5.681 tones per hour.

So, that way I have solved all the problems of the exercises. Though I have given the solutions, I have not given the solution with the idea that you just copy.

I would like to appeal to all of you, please solve yourself and only see the solution, in case you are stuck somewhere. I think you can solve the problems.

So, with the exercises and the lecture on measurement of quantities, I think I was able give you sufficient information on units and dimensions.

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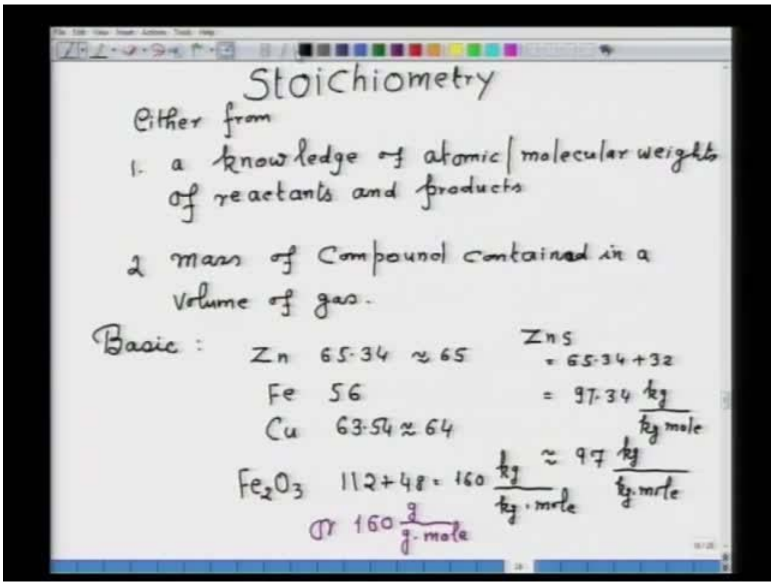


Now I will proceed to the next lecture and that is on stoichiometry. Many of the material balance problem that arise in metal extraction and refining; they can be solved either from a knowledge of atomic or molecular weights of reactants and products participating in a balanced chemical reaction.

That is, if you have the reactants; you have the product; if you know the atomic masses or the moles; you balance the equation and much information can be obtained from the atomic masses of the reactants and products that are taking part in a reaction, by making a balanced chemical equation.

That is from the law of conservation of mass; the moles which are participating, similar number of moles must also exit; that is the important.

Second, mass of compound contained in a given volume of gas.

Now, this stoichiometry can be used to develop other relationship also, as we will see in the course of the lecture.

Some of the basics, which you probably know already, I am just giving here, for the sake of completion of the lecture. Atomic mass or molecular mass, for zinc, it is 65.34. you may use approximately 65; iron, you can used 56 or to be more precise, 55.85; copper - 63.54, or you can use approximately 64 also; zinc you can use a 65.

Now, for example, if you want to calculate the molecular weight of zinc sulphide; that will be equal to 65.34 plus 32; that will be equal to 97.34. Remember the unit is kilogram per kg mole; or approximately you can also put that is 97 kilogram per kg mole.

Another example, if you want to have, say $Fe_2O_3$; that is 112 plus 48; that is equal to 160 you can write either kg per kg mole or you can also put it 160 gram per gram mole, whichever way the problem is.

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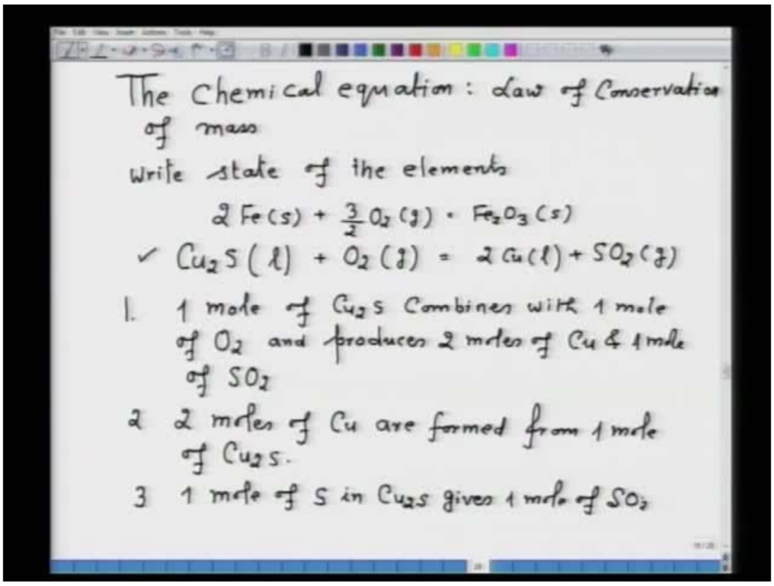


The chemical equation: let us see what we can do from writing down the chemical equation. A balance chemical equation is based on the law of conservation of mass.

Law of conservation of mass means number of atoms or elements in the product, that is equal to number of atoms or elements in the reactants; it is very a simple.

Now sometimes, it is also important to write down the state of the reactants that are taking part in reaction, to avoid the confusion. Many times, you have solid plus gas that gives you solid plus gas, that is okay; but in case solid plus gas gives liquid, then it is easier to understand the chemical equation and hence to calculate properly.

So, it is also advisable to write state of the elements participating in a reaction, in the parenthesis.

For example, if we take 2 Fe, that is solid; that is the way you write; plus 3 by 2 $O_2$, gas; that is equal to $Fe_2O_3$, solid.

This habit of writing the chemical equation, utilizing the state of the element is very helpful for various thermo physical and thermo chemical calculations in thermodynamics, because when there is a state change, then the latent heat and all those things are involved; so, if, in a equation those states are represented, you will be safe in your calculation

Similarly, if I write now, $Cu_2S$, copper sulphide, for production of copper that is in the liquid state, so you write liquid; plus it is oxidized with oxygen, which is in the gaseous state, so, you get now 2 Cu that is liquid plus $SO_2$.

Let us consider this balanced equation; that is production of copper by oxidation of copper sulphide.

We see that copper sulphide is in the liquid state; oxygen in the gaseous state; copper in the liquid state; and $SO_2$ again in the gaseous state.

This is a balanced chemical equation. From this balanced chemical equation, one can derive so much information.

Now what information do we derive from a balanced chemical equation? I am using this particular example. Now this particular equation says that 1 mole of $Cu_2S$ combines with 1 mole of oxygen and produces 2 moles of copper and 1 mole of $SO_2$.

Now I simply mentioned in terms of the moles that are taking part.

Now second information, says that 2 moles of copper 2 moles of copper are formed from 1 mole of $Cu_2S$; that also some information that you get; also you can see that 1 mole of sulphur in $Cu_2S$ gives 1 mole of $SO_2$.

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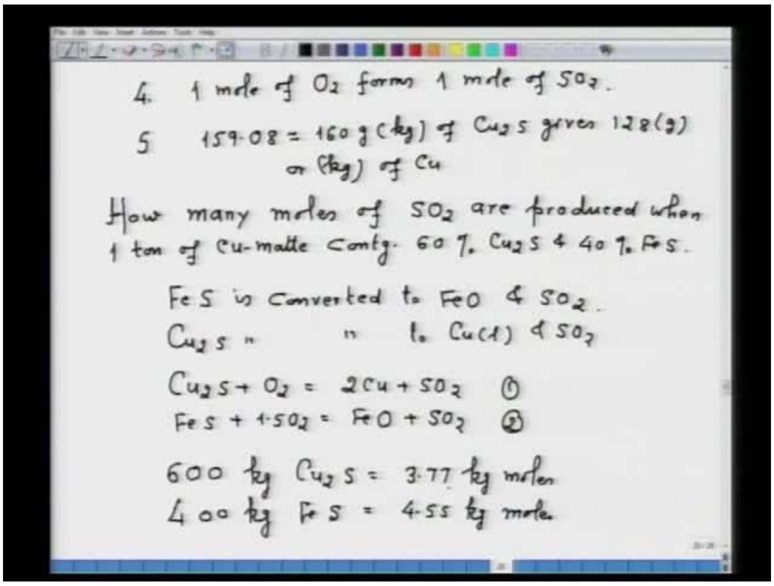


Also you can see here, fourth, 1 mole of oxygen forms 1 mole of $SO_2$. You can also write in terms of grams, if your wish

You can see from this equation that 159.08; or if you write copper's molecular weight as 64; it is equal to approximately 160 gram or kilogram of $Cu_2S$ gives 128 gram or kilogram of copper.

So similarly, you can obtain various information from the balance chemical equation.

Now, let me illustrated by giving a suitable example. See how easier it becomes to write a balance chemical equation and to proceed with the calculation, because from the balance chemical equation, you can derive so much information.

Let us see now, how many moles of $SO_2$ are produced when 1 ton of copper matte; copper matte is a liquid solution of sulphide, that is, it contains $Cu_2S$ plus FeS, that is what they matte is; 1 ton of copper matte containing 60 percent $Cu_2S$ and rest 40 percent FeS; so, we have to find out how many moles of $SO_2$ are produced?

Now here, FeS is converted to FeO and $SO_2$. $Cu_2S$ is converted to copper, liquid and $SO_2$. Now, we can write down the balance chemical equation; now say for 1 mole, you have $Cu_2S$ plus $O_2$, that is equal to 2Cu plus $SO_2$; and FeS plus 1.5 $O_2$, that is equal to Fe O plus $SO_2$.

Now, we have to substitute the different moles which are involved. So we have 1 ton; that means we have 600 kg $Cu_2S$; that is equal to 3.77 kg moles; and 400 kg FeS; that is equal to 4.55 kg moles.

So, I have to write down now, this this equation 1 and this equation 2, by utilizing the moles which are participating in the reaction.

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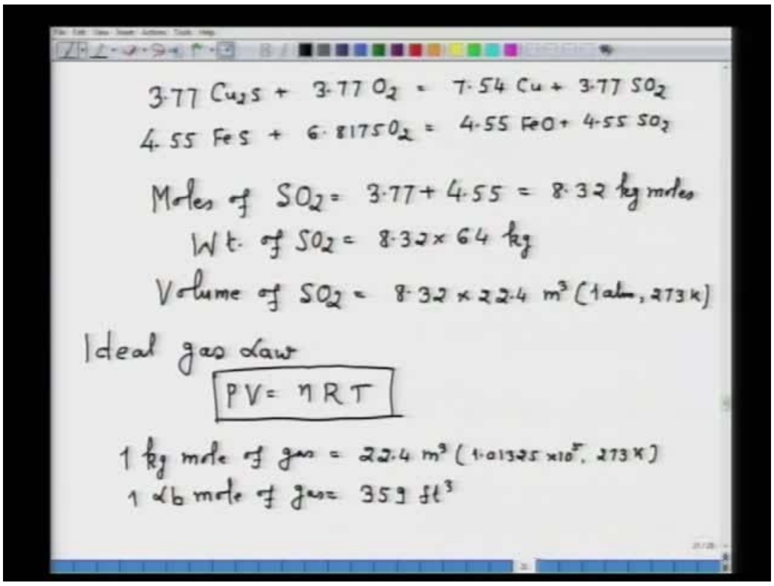


So if I do that, then I will be getting 3.77 $Cu_2S$ plus 3.77 $O_2$; that will be equal to 7.54 copper plus 3.77 $SO_2$; and 4.55 FeS plus 6.8175 $O_2$; that will be equal to 4.55 FeO plus 4.55 $SO_2$.

Now, you can straightaway find out the moles of $SO_2$ that are forming, because you written the equation in a balance form; so straightaway the ton of copper matte, which was containing 3.77 moles of $Cu_2S$ and 4.55 moles of FeS will give you the number moles of $SO_2$ equal to 3.77 plus 4.55; and that is equal to 8.32 kg moles.

Now, from here onwards, you can calculate anything; here moles of $SO_2$; but you can also calculate weight of $SO_2$. If you are interested in weight of $SO_2$ in kilogram, what do you have to do? You have to multiply 8.32 into molecular weight of $SO_2$ - 32; plus 32 - 64; so that will be weight of $SO_2$ in kg.

You can also calculate volume of $SO_2$; that will be equal to 8.32 into 22.4 meter cube expressed at 1 atmospheric pressure and 273 Kelvin.

What I want to say from here is that you can get so many information; you can also get the information like what will be the amount of oxygen that will be required for this reaction and hence what will be the amount of air that will be required to convert 1 ton of matte into copper.

So, you can straightaway calculate from here, the moles of oxygen that will be 3.77 plus 6.8175 divide by the composition of air; and in that the oxygen is 21 percent; if you divide, you get the moles of air.

What I mean to say is that you can get so many information from the balance chemical equation; that was the idea of solving this particular problem.

Now, let us take another thing, the ideal gas law. For gases, this is also very important.

The ideal gas law: Now, most gases that are taking part in our metallurgical processes; they for extraction and refining; they are at high temperatures. Typically pyro metallurgical extraction of metals involves very high temperature ranging from anywhere between 1000 to as high as 15 or 1600 degree Celsius.

So, the gases they follow the ideal gas behavior; that is P V is equal to n R T. All of you know this. It is not a very big thing, I have told you.

Now, here we can say 1 kg mole of gas is equal to 22.4 meter cube at 1.01325 into 10 to the power 5 Newton per meter square and 273 Kelvin.

That is known to all of us. Also 1 pound mole of gas is equal to 359 feet cube; I thing I had given elsewhere, but anyways this also some information.

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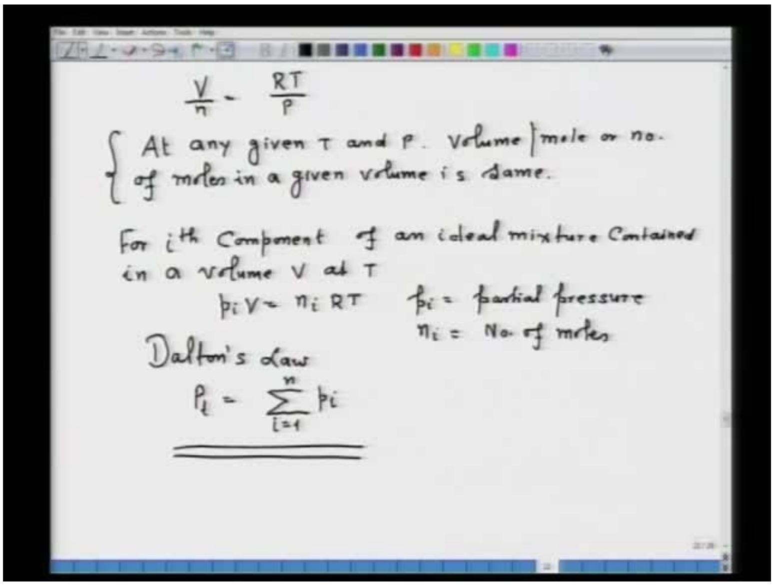

Now, we can also write down V upon n; that is equal to R T upon P; and this means that at any given temperature and pressure, volume per mole or number of moles in a given volume is same.

This, sometimes, you do require for calculation of material balance problem involving metal extraction and refining.

Just to close the lecture, I would like to tell you that in gas mixture, which are consisting of ideal gases, each component of the mixture, it also follows the ideal gas law.

So, for i th component of an ideal gas mixture contained in a volume V, at temperature T; we can write down $p_i$ into V; that is equal to $n_i$ R T; where $p_i$ is equal to partial pressure of that particular component; and $n_i$ is a number of moles of that component. So, ideal gases they follow Dalton's law; and Dalton's law simply states that total pressure $p_t$ is equal to summation 1 to n, $p_i$. Dalton's law is very important in case of gases, which are in the mixture of several components.