For my thesis project, I designed a system to increase the oxygen count in a particular volume of air. This system can be helpful in engines. Engines work by the combustion of fuel, and the combustion of fuel would not be possible without oxygen in the air. So if we were to increase the oxygen count in the air intake of an engine, there would be more combustion going on, which means a higher efficiency of the engine.

Oxygen is a paramagnetic gas. Paramagnetic materials have a magnet moments in every atom. Magnetic moments in atoms come from two properties of the atom. The first property is that electrons spin around the nucleus of an atom, and that is like a tiny current, which produces a magnetic field. The smallest value of the orbital magnetic moment is: $\mu = \sqrt{2} \cdot \frac{e \cdot h}{4 \cdot \pi \cdot m_e}$. Planck's constant is **h**, and **m** is the mass of the electron, and **e** is the elementary charge of an electron. The second property is the electron spin. An electron spinning on its own axis is also like a tiny current. The smallest value of the spin magnetic moment is: $m = \frac{e \cdot h}{4 \cdot \pi \cdot m_e} = 9.27 \cdot 10^{-24} \cdot \frac{J}{T}$. This is known as the Bohr magneton. Not all atoms have spin magnetic moments because most of the time, an electron pair has an up spin and a down spin, so the magnetic moment cancels each other out. Oxygen, however, has two electrons that spin up. The magnetic moments will line up with the magnetic field in a constant magnetic field. It takes a lot of energy to tilt an entire atom so the orbital magnetic moment lines up with the magnetic field, but takes very little to line up an electron spin magnetic moment. For this reason, we ignore the orbital magnetic moment, and only focus on the electron spin magnetic moment.

The most important property that allows us to increase the oxygen count in a certain volume of air, is that a changing magnetic field, also called a gradient magnetic field, causes a force on atoms that have magnetic moments. This force will help us direct the oxygen molecules into a direction of our choosing.

It's pretty well known that a solenoid is to a magnetic field, like a capacitor is to an electric field. A solenoid will create a constant magnetic field, in which we can use to line up the magnetic moment of the oxygen molecules. My design will consist of two solenoids: One to line up the magnetic moments of oxygen, and the second solenoid will be to control the gradient magnetic field. The design is on page twenty of this report. The big picture is that air will go through the first solenoid at a given velocity. A certain percentage of the oxygen molecules will be lined up in the constant magnetic field. The gradient field between the two solenoids will force the lined up oxygen molecules to the center of the second solenoid where a tube will be to collect the oxygen enriched air. The tube will then go wherever anyone pleases.

This report will be broken down into five parts. First, I will derive the equations of the first solenoid based on the geometry of it. Because the second solenoid will have the same equations, there will be no need to derive its equations. Next, I will need to derive a formula for the total magnetic field between the two solenoids. Once I have this equation, I can calculate the gradient field between the two solenoids. Thirdly, we will need to know the percentage of the oxygen molecules getting aligned in the first solenoid. I will show my calculations then. The fourth step is to calculate the force and deflection of the oxygen molecules. Once I have completed these four steps, I can put it all together for a final result in the fifth step, where we will find out the percentage of oxygen in the oxygen enriched air.

A final note before I begin: I chose to use a super conducting solenoid rather than a solenoid composed of copper wire. The reason is because with a copper solenoid, you have to worry about resistance, so the current will be very limited. However, for a super conducting solenoid, the resistance is zero, which means you can push as much current through as you want. This results in a much larger magnetic field for a super conducting solenoid rather than a copper solenoid. A comparison is given on pages twenty one and twenty two.

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Part 1: Formula for a solenoid based on the geometry.

The typical formula for a solenoid is: $B = \mu \cdot nl \cdot I$ where nl is the number of turns per unit length, μ is the permeability of free space, and I is the current running through the wire. Our solenoid is going to have a length (Ls), a radius (Rs1), wire with a certain radius (Rwire), and a number of overlappings (k) in which the wire is rewrapped around the solenoid k number of times. Refer to the picture on page twenty six to understand the equations.

$B = \mu \cdot n1 \cdot I$ Original equation

$nl = \frac{n}{Ls}$ Where n is equal to the total number of turns in the solenoid

$B = \mu \cdot \frac{n}{Ls} \cdot I$

$Ls = 2 \cdot Rwire \cdot n$ The length of the solenoid is equal to twice the radius of the wire times the number of turns. Plugging this back into the equation, we will get simple expression for B.

$B = \mu \cdot \frac{n}{2 \cdot Rwire \cdot n} \cdot I = \frac{\mu \cdot I}{2 \cdot Rwire}$ What this says is no matter what size solenoid you have, the only thing the magnetic field it produces depends on is the current and the radius of the wire being used. This makes since because the smaller the radius, the more wire you can fit in, which means the more current flowing through the solenoid. The more current, the larger the magnetic field.

Now lets imagine that we have two solenoids where solenoid 1 has a radius of R1 and solenoid 2 has a radius of R2. If R2 is just 2*Rwire bigger than R1, then the solenoid 1 fits right inside solenoid 2. So the total magnetic field would be the magnetic field from solenoid 1 plus the magnetic field from solenoid 2, or just twice the magnetic field of one of the solenoids. So the more solenoids we keep adding, we just multiply the total magnetic field by the number of solenoids. Now lets think of them not as separate solenoids, but as wire just being rewrapped around. This is where we get the number, k. k is the number of overlappings. For example, k = 1 means one solenoid, or just one layer of wire. k = 4 means 4 solenoids, or 4 overlappings of wire. Therefore:

$B = \frac{\mu \cdot I \cdot k}{2 \cdot Rwire}$ Where k is the number of overlappings. This is our final formula for magnetic field inside the first solenoid in my design. The magnetic field for the second solenoid will have the same formula, but with a 2 on the variables to represent its for the second solenoid. It's NOT a multiplicative of 2.

$$B2 = \frac{\mu \cdot I2 \cdot k2}{2 \cdot Rwire2}$$

EXAMPLE:

$\mu := 4 \cdot \pi \cdot 10^{-7} \cdot \frac{T \cdot m}{A}$ $Rwire := .1cm$ $I := 100 \cdot A$ $k := 40$

$B := \frac{\mu \cdot I \cdot k}{2 \cdot Rwire}$ $B = 2.513\,T$

One might be interested in how much wire we would need to make the solenoid, and also, what the outer radius of the solenoid is. Luckily, I derived those formulas also. We will call these variables Lwire and Rs

$Rs = Rs1$ When k = 1, the outer radius of the solenoid is just going to equal the inner radius of the solenoid.

$Rs = Rs1 + 2 \cdot Rwire$ When k = 2, Rs will equal Rs1 + 2 times the radius of the wire because the outer radius has increased by 1 diameter of the wire.

$Rs = Rs1 + 2 \cdot 2 \cdot Rwire$ When k = 3, Rs will equal Rs1 + 2 times 2*Rwire. We are multipling (k - 1) to Rwire everytime, which means that out final equation becomes:

$$Rs = Rs1 + (k - 1) \cdot Rwire$$

Now we are concerned with the length of the wire being used to make this solenoid.

$Lwire = 2 \cdot \pi \cdot n \cdot Rs1$ For k = 1, the length of the wire is the circumference of one loop of wire, multiplied by the number of loops of wire in the solenoid

If we added another solenoid with a radius just 2*Rwire bigger than the first solenoid, the length of the wire in the second solenoid would be:

$$Lwire = 2 \cdot \pi \cdot n \cdot (Rs1 + 2 \cdot Rwire)$$

Now add this to the first solenoid, and the total length of the wire is:

$$Lwire = 2 \cdot \pi \cdot n \cdot (Rs1 + Rs1 + 2 \cdot Rwire)$$

What happens is if you keep on adding layers of wire, you get a summation formula:

$$Lwire = 2 \cdot \pi \cdot n \cdot \left[Rs1 \cdot k + 2 \cdot Rwire \cdot \sum_{y=1}^{k} (y - 1) \right]$$

Which comes out to be:

$$Lwire = 2 \cdot \pi \cdot n \cdot \left(Rs1 \cdot k + 2 \cdot Rwire \cdot \frac{k^2 - k}{2} \right)$$

Where $n = \dfrac{Ls}{2 \cdot Rwire}$

EXAMPLE:

$Ls := 20 \cdot cm$ $Rs1 := 2 \cdot cm$

$n := \dfrac{Ls}{2 \cdot Rwire}$ $Rs := [\, Rs1 + (k - 1) \cdot Rwire \,]$

$$Lwire := 2 \cdot \pi \cdot n \cdot \left(Rs1 \cdot k + 2 \cdot Rwire \cdot \frac{k^2 - k}{2} \right)$$

$Lwire = 1482.832\,m$ $Rs = 5.9\,cm$

roughly 3.5 laps around a track

Part 2: Calculationg the magnetic field between the two solenoids

When trying to calculate the magnetic field between two solenoids, you want to break it into a couple of parts. First thing you want to think about is how do you calculate the magnetic field at the end of one solenoid? If you can do that, then the total magnetic field between the two solenoids is just a vector sumation, which is easy. So how do we do that? Well we can think of a solenoid as a loop of wire. Then if we extend the loop of wire, we will end up doing an integral. However, that is just calculating the magnetic field on the z axis. If we wanted to calculate off the z axis, we are going to have to do another integral. So from starting from the Biot Savart Law, I will derive an equation for the magnetic field at the end of a solenoid. Then, its just vector addition from there, when adding in the second solenoid. You can refer to the drawing on page ___ to make sence of the symbols.

$$\vec{B} = \frac{\mu \cdot I}{4 \cdot \pi} \cdot \int \frac{\vec{dl'} \times \vec{r}}{v(\theta,\phi)^3}\, dl$$

This is the Biot Savart Law

note that $z = R \cdot \cot(\phi)$

$$\vec{r} = (x - R \cdot \sin(\theta)) \cdot \vec{x} + (y - R \cdot \cos(\theta)) \cdot \vec{y} + (R \cdot \cot(\phi)) \cdot \vec{z}$$

where $\vec{x}$ $\vec{y}$ $\vec{z}$ are unit vectors

$$\vec{dl'} = (R \cdot \cos(\theta)) \cdot \vec{x} - (R \cdot \sin(\theta)) \cdot \vec{y} + 0 \cdot \vec{z}$$

$$v(\theta,\phi)^2 = \left(\left|\vec{r}\right|\right)^2 = R^2 + x^2 + y^2 + R^2 \cdot \cot(\phi)^2 - 2 \cdot R \cdot (x \cdot \sin(\theta) + y \cdot \cos(\theta))$$

$$\vec{dl'} \times \vec{r} = \left(-R^2 \cdot \sin(\theta) \cdot \cot(\phi) \cdot d\theta\right) \cdot \vec{x} + \left(-R^2 \cdot \cos(\theta) \cdot \cot(\phi) \cdot d\theta\right) \cdot \vec{y} + \left[-R^2 + R \cdot (x \cdot \sin(\theta) + y \cdot \cos(\theta))\right] \cdot d\theta \cdot \vec{z}$$

For the next part, I will be splitting the integral into the 3 x,y,z vector components.

X COMPONENT:

$$\vec{Bx} = \frac{-\mu \cdot I \cdot R^2}{4 \cdot \pi} \cdot \int_0^{2 \cdot \pi} \frac{\sin(\theta) \cdot \cot(\phi)}{\left[R^2 + x^2 + y^2 + R^2 \cdot \cot(\phi)^2 - 2 \cdot R \cdot (x \cdot \sin(\theta) + y \cdot \cos(\theta))\right]^{\frac{3}{2}}}\, d\theta$$

ok this is good for now, but now we have to plug in the fact that I = n*I*dz

$$z = R \cdot \cot(\phi)$$

$$dz = \frac{-R}{\sin(\phi)^2} \cdot d\phi$$

$$\vec{Bx} = \frac{\mu \cdot I \cdot n \cdot R^3}{4 \cdot \pi} \cdot \int_{\phi 1}^{\phi 2} \int_0^{2 \cdot \pi} \frac{\sin(\theta) \cdot \cot(\phi)}{\sin(\phi)^2 \cdot \left[R^2 + x^2 + y^2 + R^2 \cdot \cot(\phi)^2 - 2 \cdot R \cdot (x \cdot \sin(\theta) + y \cdot \cos(\theta))\right]^{\frac{3}{2}}}\, d\theta\, d\phi$$

Y COMPONENT

$$\vec{By} = \frac{-\mu \cdot I \cdot R^2}{4 \cdot \pi} \cdot \int_0^{2\cdot\pi} \frac{\cos(\theta)\cdot\cot(\phi)}{\left[R^2 + x^2 + y^2 + R^2\cdot\cot(\phi)^2 - 2\cdot R\cdot(x\cdot\sin(\theta) + y\cdot\cos(\theta))\right]^{\frac{3}{2}}}\, d\theta$$

$I = n \cdot I \cdot dz$

$z = R \cdot \cot(\phi)$

$dz = \frac{-R}{\sin(\phi)^2} \cdot d\phi$

$$\vec{By} = \frac{\mu \cdot I \cdot n \cdot R^3}{4 \cdot \pi} \cdot \int_{\phi1}^{\phi2} \int_0^{2\cdot\pi} \frac{\cos(\theta)\cdot\cot(\phi)}{\sin(\phi)^2\cdot\left[R^2 + x^2 + y^2 + R^2\cdot\cot(\phi)^2 - 2\cdot R\cdot(x\cdot\sin(\theta) + y\cdot\cos(\theta))\right]^{\frac{3}{2}}}\, d\theta\, d\phi$$

Z COMPONENT

$$\vec{Bz} = \frac{\mu \cdot I}{4 \cdot \pi} \cdot \int_0^{2\cdot\pi} \frac{-R^2 + R\cdot(x\cdot\sin(\theta) + y\cdot\cos(\theta))}{\left[R^2 + x^2 + y^2 + R^2\cdot\cot(\phi)^2 - 2\cdot R\cdot(x\cdot\sin(\theta) + y\cdot\cos(\theta))\right]^{\frac{3}{2}}}\, d\theta$$

$I = n \cdot I \cdot dz$

$z = R \cdot \cot(\phi)$

$dz = \frac{-R}{\sin(\phi)^2} \cdot d\phi$

$$\vec{Bz} = \frac{-R^2 \cdot \mu \cdot I \cdot n}{4 \cdot \pi} \cdot \int_{\phi1}^{\phi2} \int_0^{2\cdot\pi} \frac{-R + (x\cdot\sin(\theta) + y\cdot\cos(\theta))}{\sin(\phi)^2\cdot\left[R^2 + x^2 + y^2 + R^2\cdot\cot(\phi)^2 - 2\cdot R\cdot(x\cdot\sin(\theta) + y\cdot\cos(\theta))\right]^{\frac{3}{2}}}\, d\theta\, d\phi$$

The three highlighted equations above are the x, y, and z vector components of the magnetic field at the end of a solenoid. Now lets see how we get a gradient magnetic field out of these equations. Keep in mind, that I left these equations in integral form because they are very difficult to solve symbolically, however mathcad can just calculate values as they are.

Calculating a gradient field is easy. But before we can do that, we need to know what the total magnetic field is for the solenoid. To find that, all we do is add the vector components above.

$$\vec{Bt} = \vec{Bx} + \vec{By} + \vec{Bz}$$

A gradient takes a scalar quantity and turns it into a vector quantity. So what we have to do first is turn our total magnetic field vector into a scalar quantity.

$$Bt = \sqrt{Bx^2 + By^2 + Bz^2} \qquad \text{or} \qquad Bt = \left|\vec{Bt}\right|$$

Now we can calculate the magnetic gradient field:

$$GradBt = \begin{pmatrix} \frac{d}{dx}Bt \\ \frac{d}{dy}Bt \\ \frac{d}{dz}Bt \end{pmatrix}$$

This will give us units of Tesla/meter

Now if we had two solenoids, the total magnetic field would just be the sum of the two magnetic fields from the solenoids, and the gradient field would just be derivitives of total magnetic field:

$$Bt = \left|\vec{Bt1} + \vec{Bt2}\right|$$

$$GradBt = \begin{pmatrix} \frac{d}{dx}Bt \\ \frac{d}{dy}Bt \\ \frac{d}{dz}Bt \end{pmatrix}$$

PART 3) % of the oxygen molecules aligned in the constant magnetic field

For this part, we have to include a variable called the magnetic susceptibility χ. For paramagnetic materials, χ is a unitless, positive number. There are other materials with a magnetic dipole that point in the OPPOSITE direction of the magnetic field, and these materials are known as diamagnetic materials. Nitrogen gas is a diamagnetic material. They also have a magnetic susceptibility, but its value is a negative one. χ for nitrogen has a magnitude which is 10^3 times smaller than that of oxygen, so for the purpose of my calculations, I will not be including them. However, if I was, we would find out that while oxygen was being forced into the center of the second solenoid due to the gradient field, nitrogen would have an opposite reaction and would be forced outside the second solenoid. This would increase the oxygen count in the air even more. But because the susceptibility is so small, its not really worth it at this point. In the mean time, lets figure out how many oxygen molecules would line up.

$\chi := 2.1\cdot 10^{-6}$ This is the magnetic susceptibility of Oxygen gas at 300K

$P := 1\cdot \mathrm{atm}$ Gas pressure of the air inside the solenoid

$\mathrm{Temp} := 300\cdot K$ Temperature of the air

$R := 8.31451\cdot \frac{J}{K\cdot \mathrm{mol}}$ Gas Constant

$N := 6.0221367\cdot 10^{23}\cdot \frac{1}{\mathrm{mol}}$ Number of atoms or molecules in a mole. Avogadro's #

These percentages are *mass* percentages in air

$\%O2 := 23.2\%$

$\%N2 := 75.47\%$

$\%Ar := 1.28\%$

These are the molecular wieghts of each

$O2 := 32\cdot \frac{g}{\mathrm{mol}}$ $Ar := 39.95\cdot \frac{g}{\mathrm{mol}}$ $N2 := 28.01\cdot \frac{g}{\mathrm{mol}}$

The mass of 1 oxygen molecule

$\mathrm{mass\_1O2} := \frac{O2}{N}$ $\mathrm{mass\_1O2} = 5.314\times 10^{-26}\,\mathrm{kg}$

The volume of an O2 molecule: $\rho O2 := 1.43\cdot \frac{\mathrm{kg}}{m^3}$ $VO2 := \frac{\mathrm{mass\_1O2}}{\rho O2}$ $VO2 = 3.716\times 10^{-26}\,m^3$

This is the molecular weight of Air.

$\mathrm{Mair} := \%O2\cdot O2 + \%N2\cdot N2 + \%Ar\cdot Ar$ $\mathrm{Mair} = 29.075\,\frac{1}{\mathrm{mol}}\,g$

I'm ignoring all the other gases in air, The real molecular weight value of air is around 28.98 g/mol

This is the density of Air

$\rho\mathrm{air} := \frac{P\cdot \mathrm{Mair}}{R\cdot \mathrm{Temp}}$ $\rho\mathrm{air} = 1.181\times 10^{-3}\,\frac{g}{\mathrm{cm}^3}$

$Ls := 50\cdot \mathrm{cm}$

$Rs1 := 3\cdot \mathrm{cm}$

Magnetic dipole of 1 O2 molecule

$\mathrm{m\_dipole} := 18.54\cdot 10^{-24}\cdot \frac{J}{T}$

This is an estimated value. I came up with it because oxygen has two unpaired electrons that point in the same direction. So I multiplied the electron spin magnetic moment by 2

Volume of the soleniod

$V := \pi \cdot Rs1^2 \cdot Ls$ $\qquad V = 1.414 \times 10^3\,cm^3$

mass of the air in the solenoid

$mass\_air := \rho air \cdot V$ $\qquad mass\_air = 1.67\,g$

Mass of O2 in the air in the solenoid

$mass\_O2 := mass\_air \cdot \%O2$ $\qquad mass\_O2 = 0.387\,g$

number of O2 molecules in the solenoid with a volume V

$n\_O2 := \frac{mass\_O2 \cdot N}{O2}$ $\qquad n\_O2 = 7.29 \times 10^{21}$

The maximum magnetization

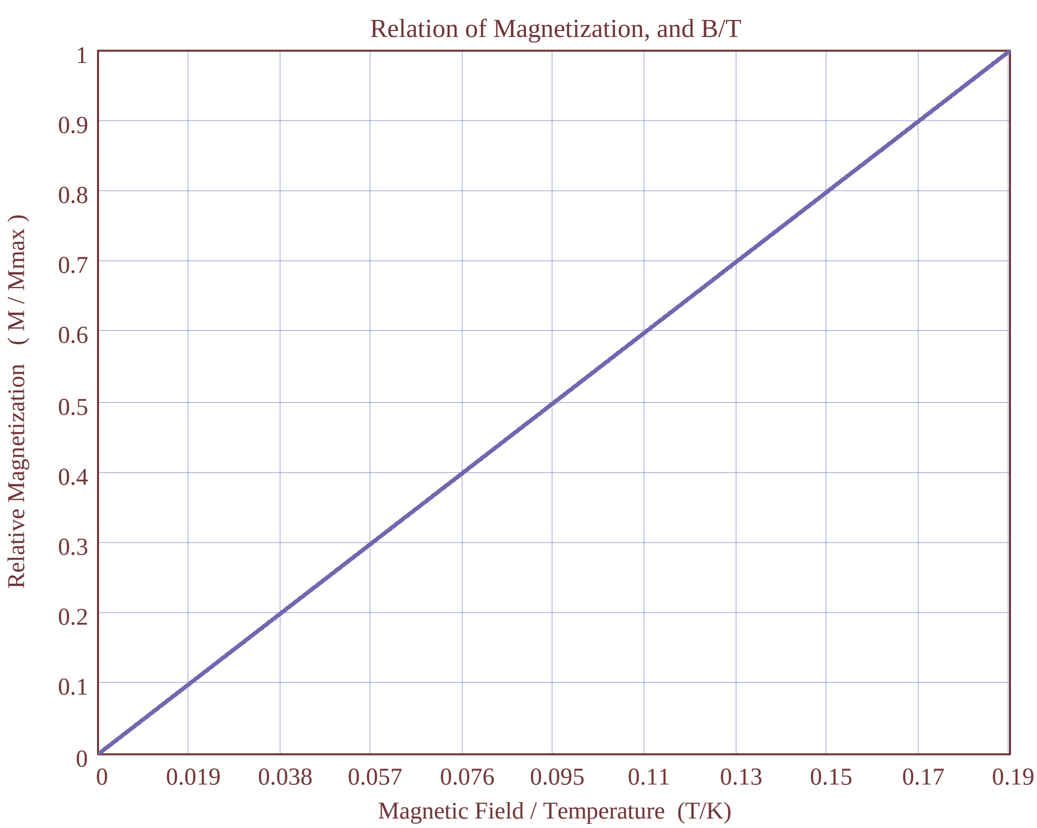
$M\_max := \frac{n\_O2}{V} \cdot m\_dipole$ $\qquad M\_max = 9.56 \times 10^{-5} \frac{J}{T \cdot cm^3}$

$slope := \frac{\chi \cdot Temp}{M\_max \cdot \mu}$ This slope gives me the slope of Curie's Law for my particular values of O2, and tempurature.

Below, is the relationship between the magnetization, and the values for B/T. I can assume a straight line relation because the curie law is good for low values of B. However, at High values of B/T, it breaks down. But since our Temp = 300K, we are not going to get too high of a value seeing as our B field is roughly only around 2.5T

$slope = 5.244 \frac{K}{T}$

$C(x) := slope \cdot x$



$B := 2.513 \cdot T$ This value is from the first part of this report.

x is the value of the magnetic field over tempurature. (B / Temp) I can use this, and plug in values and get the % of oxygen molecules aligned.

$$x := \frac{B}{Temp}$$

$$C(x) = 0.044$$

$$\%O2\_aligned := C(x)$$

$\%O2\_aligned = 4.393\,\%$ This doesn't seem to be too high of a number, but lets see how many oxygen molecules it is for our particular example

$$n\_O2 = 7.29 \times 10^{21}$$

$n\_O2 \cdot \%O2\_aligned = 3.202 \times 10^{20}$ Thats a pretty big number

Part 4) Force Equation, and deflection

This was probably the hardest part of the thesis here. There were no force formulas that stuck out online, nor were there any in the book for a gradient magnetic field. So what I did was start with a known equation, and tried to end up with a result close to what I would expect it to be. Basically, I had to derive the formula my self much like I did with the magnetic field equations. I started with a known formula, known as the Biot Savart Law. Rather than doing the force over a whole system, I did the force on one oxygen molecule, which I'll explain why later.

$F = \mathrm{Grad}\left(\vec{m} \cdot \vec{B}\right)$ This is the force equation I started with. $\vec{m}$ is an Infinitesimal magnetic moment, and $\vec{B}$ is the magnetic field that the particle is in. In our case, the particle is the oxygen molecule.

Because m and B are pointing in the same direction, we can get rid of the vector signs and treat them as scalars.

$F = \mathrm{Grad}(m \cdot B)$ This works because the gradient of a scalar gives a vector. Next, I will be doing some algebraic properties.

$\vec{M} = \frac{\vec{m}}{V} = \chi \cdot \vec{H}$ M is the magnetization vector, V is the volume of an oxygen molecule, H is the magnetic field strength, and χ is the magnetic susceptibility.

$\vec{H} = \frac{\vec{Bo}}{\mu}$ Bo is a constant magnetic field pointing in the z direction, produced by the first solenoid

$\frac{\vec{m}}{V} = \chi \cdot \frac{\vec{Bo}}{\mu}$ Solving for m, we get: $\vec{m} = \chi \cdot V \cdot \frac{\vec{Bo}}{\mu}$ But we are just dealing with the scalar quantity, therefore......

$m = \chi \cdot V \cdot \frac{Bo}{\mu}$ Plugging this back into the force formula, we get: $F = \mathrm{Grad}\left(\chi \cdot V \cdot \frac{Bo}{\mu} \cdot B\right)$

However, since there are 4 constants in there, we can bring them out of the gradient field. The only thing that is changing is the magnetic field on the end of the solenoid, which is represented by B.

$$\vec{F} = \chi \cdot V \cdot \frac{Bo}{\mu} \cdot \mathrm{Grad}(B)$$

When I plug in values for the force all around the solenoid, what happens is that the oxygen molecules are forced inward towards the center of the second solenoid. So we can make a tube to catch all the aligned oxygen molecules.

The downside to this design is that the gradient field does not produce a constant Force. The force is always changing. It depends on all three components of where the oxygen molecule is (x,y,z). The Force is strongest at z = 0, and gradually gets weaker. It does cross a point where z roughly equals 7/8 *d where the force becomes 0. The force then becomes negative, and this makes since because the magnetic field is changing direction once it enters the second solenoid. An example of what the force does is on page twenty three. In order to make calculations easier for me, what I did was take the average force, and assume that force was constant throughout the entire region. Though my answers will not be correct, they will be a pretty good estimate. Another simplification I made when doing the deflection calculation is to just calculate the deflection of 1 oxygen molecule on the outside part of the first solenoid. As you get closer to the z axis (R --> 0), the force becomes weaker. So if I can find the deflection of a particle from the outside part of the solenoid, all the particles inside the radius will also be deflected inwards. Also note that because we are dealing with a circular design, all the particles around the tube will act in the same way. Based on the deflection, I can decide how big the tube has to be to catch all the of the aligned oxygen molecules. On the next page, I will show how I calculate the deflection, and how this will give us the oxygen count in the oxygen enriched air.

$\vec{F} = \mathrm{mass} \cdot \vec{a}$ First we start with this elementary equation and solve for the acceleration

$\vec{a} = \frac{Ff}{mass\_1O2}$ Remember that mass_1O2 is the mass of one oxygen molecule. Also note that because F is a vector quantity, a will also be a vector

$Voz := 1.2 \cdot \frac{m}{s}$ This is the velocity of the air coming into the first solenoid

$ay = (\vec{a})_1$ This is the acceleration in the y direction

$az = (\vec{a})_2$ This is the acceleration in the z direction

$zf = \frac{7}{8} \cdot d$ This is the position we will start our tube at because the force will turn negative after it goes farther than this amount and we don't want the oxygen molecules to start spreading back out. For the rest of the calculations, you can refer to the picture on page twenty four to understand the equations.

$$zf = Voz \cdot t + \frac{1}{2} \cdot az \cdot t^2$$

$$t = \frac{1}{2 \cdot az} \cdot \left[-2 \cdot Voz + 2 \cdot \left(Voz^2 + 2 \cdot az \cdot zf \right)^{\frac{1}{2}} \right]$$

After using mathcad to solve for t using the position equations, this is what i get.

$yf = \frac{1}{2} \cdot ay \cdot t^2$ This is the deflection of the oxygen molecule from the outermost part of the first solenoid

$Rtube = Rs1 - yf$ This will decide how big the Radius is for the tube that collects all the oxygen.

Alright, so if I build a tube and start it at 7/8 * d, and give it a radius of Rtube, then I would have gotten the extra % of air molecules in the tube - the nitrogen molecules that it pushes out, but I have yet to calculate that.

$Vtube = \pi \cdot (Rtube)^2 \cdot Ltube$ Ltube is the length of the tube

mass of the air in the Tube

$$mass\_air = \rho air \cdot Vtube$$

Mass of O2, N2, Ar in the air in the Tube

$$mass\_O2 = mass\_air \cdot \%O2$$

$$mass\_N2 = mass\_air \cdot \%N2$$

$$mass\_Ar = mass\_air \cdot \%Ar$$

Mass of the aligned oxygen molecules coming from the first solenoid

$$massO2\_aligned = n\_O2 \cdot \%O2\_aligned \cdot mass\_1O2$$

$$Mass\_airtube = mass\_O2 + mass\_N2 + mass\_Ar + massO2\_aligned$$

$$\frac{massO2\_aligned + mass\_O2}{Mass\_airtube} = \%$$

This is it!!!!!! Lets put it all together now, which is in the next section of this report. I'm just going to plug in random values. We can make the system as large as we want, or as small. It really depends on the cost of the materials, availability of the materials, and the size limit.

5th part of the report, putting everything together

$\mu := 4\cdot\pi\cdot 10^{-7}\cdot\frac{T\cdot m}{A}$

Everything highlighted in yellow are variables that you can change.

DEMINSIONS OF BOTH THE SOLENIODS WHERE THE 2 REPRESENTS THE SOLENIOD ON THE RIGHT

$k := 50$	$k2 := 40$	number of overlappings
$I := 120\cdot A$	$I2 := 140\cdot A$	Current through the solenoid
$Rwire := .1cm$	$Rwire2 := .1cm$	Radius of the wire being used
$Rs1 := 3\cdot cm$	$Rs2 := 4\cdot cm$	Radius from the center of the solenoid to the first layer of wire (k = 1)
$Ls := 50\cdot cm$	$Ls2 := 50\cdot cm$	Length of the solenoid
$n := \frac{Ls}{2\cdot Rwire}$	$n2 := \frac{Ls2}{2\cdot Rwire2}$	number of turns the solenoid has
$Lwire := 2\cdot\pi\cdot n\cdot\left(Rs1\cdot k + 2\cdot Rwire\cdot\frac{k^2 - k}{2}\right)$	$Lwire2 := 2\cdot\pi\cdot n2\cdot\left(Rs2\cdot k2 + 2\cdot Rwire2\cdot\frac{k2^2 - k2}{2}\right)$	Length of the wire needed to make the solenoid
$Rs := Rs1 + (k-1)\cdot 2\cdot Rwire$	$Rs22 := Rs2 + (k2-1)\cdot 2\cdot Rwire2$	Total radius of the solenoid from center to k = max(k)

POSITIONS AROUND SOLENOID

$x := 0\cdot cm$ $y := -2\cdot cm$ $z := 3\cdot cm$ $d := 6\cdot cm$

Here, d is the distance between the faces of the two solenoids. ϕ is for the first solenoid on the left, and α is fore the second solenoid on the right.

$\phi1(z) := \operatorname{acot}\left(\frac{z}{Rs1}\right)$ $\alpha1(z) := \operatorname{acot}\left(\frac{d-z}{Rs2}\right)$

$\phi2(z) := \operatorname{acot}\left(\frac{z+Ls}{Rs1}\right)$ $\alpha2(z) := \operatorname{acot}\left(\frac{d-z+Ls2}{4\cdot cm}\right)$

$\phi1(z) = 45\,deg$ $\alpha1(z) = 53.13\,deg$

$\phi2(z) = 3.24\,deg$ $\alpha2(z) = 4.316\,deg$

EQUATIONS FOR THE LEFT SIDE SOLENOID

$$Bx1(x,y,z) := \frac{-\mu\cdot I\cdot Rs1^3\cdot k}{8\cdot\pi\cdot Rwire}\cdot\int_{\phi1(z)}^{\phi2(z)}\int_0^{2\cdot\pi}\frac{\sin(\theta)\cdot\cot(\phi)}{\sin(\phi)^2\cdot\left[Rs1^2 + x^2 + y^2 + Rs1^2\cdot\cot(\phi)^2 - 2\cdot Rs1\cdot(x\cdot\sin(\theta) + y\cdot\cos(\theta))\right]^{\frac{3}{2}}}\,d\theta\,d\phi$$

$$By1(x,y,z) := \frac{-\mu \cdot I \cdot Rs1^3 \cdot k}{8 \cdot \pi \cdot Rwire} \cdot \int_{\phi 1(z)}^{\phi 2(z)} \int_0^{2\cdot\pi} \frac{\cos(\theta)\cdot\cot(\phi)}{\sin(\phi)^2 \cdot \left[Rs1^2 + x^2 + y^2 + Rs1^2 \cdot \cot(\phi)^2 - 2\cdot Rs1 \cdot (x\cdot\sin(\theta) + y\cdot\cos(\theta))\right]^{\frac{3}{2}}} \, d\theta \, d\phi$$

$$Bz1(x,y,z) := \frac{Rs1^2 \cdot \mu \cdot I \cdot k}{8 \cdot \pi \cdot Rwire} \cdot \int_{\phi 1(z)}^{\phi 2(z)} \int_0^{2\cdot\pi} \frac{-Rs1 + (x\cdot\sin(\theta) + y\cdot\cos(\theta))}{\sin(\phi)^2 \cdot \left[Rs1^2 + x^2 + y^2 + Rs1^2 \cdot \cot(\phi)^2 - 2\cdot Rs1 \cdot (x\cdot\sin(\theta) + y\cdot\cos(\theta))\right]^{\frac{3}{2}}} \, d\theta \, d\phi$$

$$B1(x,y,z) := \begin{pmatrix} Bx1(x,y,z) \\ By1(x,y,z) \\ Bz1(x,y,z) \end{pmatrix} \quad B1(x,y,z) = \begin{pmatrix} 4.961 \times 10^{-17} \\ -0.193 \\ 0.443 \end{pmatrix} T$$

EQUATIONS FOR THE RIGHT SIDE SOLENOID

$$Bx2(x,y,z) := \frac{-\mu \cdot I2 \cdot Rs2^3 \cdot k2}{8 \cdot \pi \cdot Rwire2} \cdot \int_{\alpha 1(z)}^{\alpha 2(z)} \int_0^{2\cdot\pi} \frac{\sin(\theta)\cdot\cot(\alpha)}{\sin(\alpha)^2 \cdot \left[Rs2^2 + x^2 + y^2 + Rs2^2 \cdot \cot(\alpha)^2 - 2\cdot Rs2 \cdot (x\cdot\sin(\theta) + y\cdot\cos(\theta))\right]^{\frac{3}{2}}} \, d\theta \, d\alpha$$

$$By2(x,y,z) := \frac{-\mu \cdot I2 \cdot Rs2^3 \cdot k2}{8 \cdot \pi \cdot Rwire2} \cdot \int_{\alpha 1(z)}^{\alpha 2(z)} \int_0^{2\cdot\pi} \frac{\cos(\theta)\cdot\cot(\alpha)}{\sin(\alpha)^2 \cdot \left[Rs2^2 + x^2 + y^2 + Rs2^2 \cdot \cot(\alpha)^2 - 2\cdot Rs2 \cdot (x\cdot\sin(\theta) + y\cdot\cos(\theta))\right]^{\frac{3}{2}}} \, d\theta \, d\alpha$$

$$Bz2(x,y,z) := \frac{Rs2^2 \cdot \mu \cdot I2 \cdot k2}{8 \cdot \pi \cdot Rwire2} \cdot \int_{\alpha 1(z)}^{\alpha 2(z)} \int_0^{2\cdot\pi} \frac{-Rs2 + (x\cdot\sin(\theta) + y\cdot\cos(\theta))}{\sin(\alpha)^2 \cdot \left[Rs2^2 + x^2 + y^2 + Rs2^2 \cdot \cot(\alpha)^2 - 2\cdot Rs2 \cdot (x\cdot\sin(\theta) + y\cdot\cos(\theta))\right]^{\frac{3}{2}}} \, d\theta \, d\alpha$$

$$B2(x,y,z) := \begin{pmatrix} Bx2(x,y,z) \\ By2(x,y,z) \\ Bz2(x,y,z) \end{pmatrix} \qquad B2(x,y,z) = \begin{pmatrix} 5.106 \times 10^{-17} \\ -0.212 \\ 0.616 \end{pmatrix} T$$

COMBINING THE SOLENOIDS

$\mathrm{Bt}(x,y,z) := \mathrm{B1}(x,y,z) + \mathrm{B2}(x,y,z)$

The magnetic field between the solenoid is simply just vector addition. Bt stands for the total magnetic field.

$$\mathrm{Bt}(x,y,z) = \begin{pmatrix} 1.007\times 10^{-16} \\ -0.405 \\ 1.06 \end{pmatrix} \mathrm{T}$$

NOTE:
1) If i choose the current to be negative in one of the solenoids with same values for everything else, i should get a Bt of 0, which I do.
2) If i choose d = 0, and z = 0, α1 and ϕ1 should = 90 degrees, and if i choose Ls1 = Ls2 = a very large number, i should get Bt = B, which I do

$$B := \frac{\mu\cdot I\cdot k}{2\cdot \mathrm{Rwire}} \qquad B = 3.77\,\mathrm{T}$$

GRADIENT FIELD AND FORCE EQUATIONS

$$\left|\mathrm{Bt}(x,y,z)\right| = 1.135\,\mathrm{T}$$

$$\mathrm{GradBt} := \begin{pmatrix} \frac{d}{dx}\left|\mathrm{Bt}(x,y,z)\right| \\ \frac{d}{dy}\left|\mathrm{Bt}(x,y,z)\right| \\ \frac{d}{dz}\left|\mathrm{Bt}(x,y,z)\right| \end{pmatrix}$$

$$\mathrm{GradBt} = \begin{pmatrix} 0 \\ 0.113 \\ 0.027 \end{pmatrix} \frac{\mathrm{T}}{\mathrm{cm}}$$

This is the gradient magnetic field at a certain x,y,z

$\chi := 2.1\cdot 10^{-6}$

$P := 1\cdot \mathrm{atm}$

$\mathrm{Temp} := 300\cdot \mathrm{K}$

$$R := 8.31451\cdot \frac{\mathrm{J}}{\mathrm{K}\cdot \mathrm{mol}}$$

$$N := 6.0221367\cdot 10^{23}\cdot \frac{1}{\mathrm{mol}}$$

These percentages are mass percentages in air

$\%O2 := 23.2\%$

$\%N2 := 75.47\%$

$\%Ar := 1.28\%$

These are the molecular wieghts of each

$$O2 := 32\cdot \frac{g}{\mathrm{mol}} \qquad Ar := 39.95\cdot \frac{g}{\mathrm{mol}} \qquad N2 := 28.01\cdot \frac{g}{\mathrm{mol}}$$

The mass of 1 oxygen molecule

$$\mathrm{mass\_1O2} := \frac{O2}{N} \qquad \mathrm{mass\_1O2} = 5.314\times 10^{-26}\,\mathrm{kg}$$

The volume of an O2 molecule: $\rho O2 := 1.43 \cdot \frac{kg}{m^3}$ $VO2 := \frac{mass\_1O2}{\rho O2}$ $VO2 = 3.716 \times 10^{-26}\, m^3$

This is the molecular weight of Air.

$Mair := \%O2 \cdot O2 + \%N2 \cdot N2 + \%Ar \cdot Ar$ $Mair = 29.075 \frac{1}{mol} g$

This is the density of Air

$\rho air := \frac{P \cdot Mair}{R \cdot Temp}$ $\rho air = 1.181 \times 10^{-3} \frac{g}{cm^3}$

Magnetic dipole of 1 O2 molecule

$m\_dipole := 18.54 \cdot 10^{-24} \cdot \frac{J}{T}$

Volume of the 1st soleniod

$V := \pi \cdot Rs1^2 \cdot Ls$ $V = 1.414 \times 10^3\, cm^3$

mass of the air in the 1st solenoid

$mass\_air := \rho air \cdot V$ $mass\_air = 1.67\, g$

Mass of O2 in the air in the 1st solenoid

$mass\_O2 := mass\_air \cdot \%O2$ $mass\_O2 = 0.387\, g$

number of O2 molecules in the solenoid with a volume V

$n\_O2 := \frac{mass\_O2 \cdot N}{O2}$ $n\_O2 = 7.29 \times 10^{21}$

The maximum magnetization

$M\_max := \frac{n\_O2}{V} \cdot m\_dipole$ $M\_max = 9.56 \times 10^{-5} \frac{J}{T \cdot cm^3}$

$$slope := \frac{\chi \cdot Temp}{M\_max \cdot \mu}$$

$$slope = 5.244 \frac{K}{T}$$

$$C(x) := slope \cdot x$$

$$x := \frac{B}{Temp}$$

$$C(x) = 0.066$$

$$\%O2\_aligned := C(x)$$

$$\%O2\_aligned = 6.59\, \%$$

$$Ff := \frac{VO2\cdot\chi}{\mu}\cdot(B\cdot GradBt)$$

$$Ff = \begin{pmatrix} 0 \\ 2.645\times 10^{-24} \\ 6.308\times 10^{-25} \end{pmatrix} N$$

The force is actually not constant, so what i do is set of values and take the average force.

$$a := \frac{Ff}{mass\_1O2}$$

$$a = \begin{pmatrix} 0 \\ 49.773 \\ 11.87 \end{pmatrix} \frac{m}{s^2}$$

$Voz := 1.4\cdot\frac{m}{s}$ This is the velocity of the air coming into the first solenoid

$ay := a_1$ This is the acceleration in the y direction

$az := a_2$ This is the acceleration in the z direction

$$zf := \frac{7}{8}\cdot d$$

$$t := \frac{1}{2\cdot az}\cdot\left[-2\cdot Voz + 2\cdot\left(Voz^2 + 2\cdot az\cdot zf\right)^{\frac{1}{2}}\right]$$

After using mathcad to solve for t using the position equations, this is what i get.

$yf := \frac{1}{2}\cdot ay\cdot t^2$ This will decide how big the Radius is for the tube that collects all the oxygen.

$yf = 2.695\,cm$ $Rtube := Rs1 - yf$ $Rtube = 0.305\,cm$

$Ltube := 100\cdot cm$

$$Vtube := \pi\cdot(Rtube)^2\cdot Ltube$$

mass of the air in the Tube

$mass\_air := \rho air \cdot Vtube$ $\qquad mass\_air = 0.034\,g$

Mass of O2, N2, Ar in the air in the Tube

$mass\_O2 := mass\_air \cdot \%O2$ $\qquad mass\_O2 = 7.999 \times 10^{-3}\,g$

$mass\_N2 := mass\_air \cdot \%N2$ $\qquad mass\_N2 = 0.026\,g$

$mass\_Ar := mass\_air \cdot \%Ar$ $\qquad mass\_Ar = 4.413 \times 10^{-4}\,g$

Mass of the aligned oxygen molecules coming from the first solenoid

$massO2\_aligned := n\_O2 \cdot \%O2\_aligned \cdot mass\_1O2$ $\qquad massO2\_aligned = 2.553 \times 10^{-5}\,kg$

$Mass\_airtube := mass\_O2 + mass\_N2 + mass\_Ar + massO2\_aligned$ $\qquad Mass\_airtube = 0.06\,g$

$\frac{massO2\_aligned + mass\_O2}{Mass\_airtube} = 55.888\,\%$ This is the % of air in the tube now, compared to $\%O2 = 23.2\,\%$

Keep in mind, this is the % if the N2 molecules are not affected by the magnetic field. So this % in reality would be a tad bit higher. Also keep in mind this has to do with the volume of the tube. The smaller volume of the tube, the bigger the % will be. If the tube volume is just as large as the first solenoid, then there will be no % change.

Other values

$Lwire = 6.205\,km$ $\qquad Lwire2 = 4.964\,km$ Thats a lot of wire

$Rs = 12.8\,cm$ $\qquad Rs22 = 11.8\,cm$

$B = 3.77\,T$ Value of the first solenoid

$Vtube = 29.192\,cm^3$

Comparing super and normal conducting solenoids

Constant Variables:

Reference Temperature: $Tempo := (20 + 273.15)\cdot K$

Permeability of free space: $\mu := 4\cdot\pi\cdot 10^{-7}\cdot\frac{T\cdot m}{A}$

Temperature Coefficient of Resistivity: $\alpha := 3.8\cdot 10^{-3}\cdot\frac{1}{K}$

This is for Copper

Reference Resistivity: $\rho o := 1.7\cdot 10^{-8}\cdot\Omega\cdot m$

Changing Variables for a normal solenoid

$k := 40$ Number of overlapping

$Volt := 40\cdot V$ Given Voltage Source

$Rwire := .1cm$ Radius of the given wire

$Rs1 := .04\cdot m$ Inside radius of Soleniod

$Ls := .1\cdot m$ Length of the Soleniod

$Temp := (0 + 273.15)\cdot K$ Temperature of the material

Changing Variables for a Superconductor

$sk := 40$

$sI := 100\cdot A$

$sRwire := .1cm$

$sRs1 := .04\cdot m$

$sLs := .1\cdot m$

Equations for a normal solenoid

$$n := \frac{Ls}{2\cdot Rwire}$$

$\rho := \rho o\cdot\left[1 + \alpha\cdot(Temp - Tempo)\right]$ Resistivity of the wire

$$Lwire := 2\cdot\pi\cdot n\cdot\left(Rs1\cdot k + 2\cdot Rwire\cdot\frac{k^2 - k}{2}\right)$$

$$Rs := Rs1 + (k - 1)\cdot 2\cdot Rwire$$

$Resistance := \frac{\rho\cdot Lwire}{\pi\cdot Rwire^2}$ Resistance of the Wire

$I := \frac{Volt}{Resistance}$ Current running through the wire based on Voltage and Resistance

$B := \frac{\mu\cdot n\cdot I\cdot k}{Ls}$ Magnetic Field produced by Preceding equations

Equations for a Superconductor

$$sB := \frac{\mu\cdot sI\cdot sk}{2\cdot sRwire}$$

$$sn := \frac{sLs}{2\cdot sRwire}$$

$$sLwire := 2\cdot\pi\cdot sn\cdot\left(sRs1\cdot sk + 2\cdot sRwire\cdot\frac{sk^2 - sk}{2}\right)$$

$$sRs := sRs1 + (sk - 1)\cdot 2\cdot sRwire$$

Results for a normal solenoid

$B = 0.203\,T$

$n = 50$

$Rwire = 1 \times 10^{-3}\,m$

$k = 40$

$Ls = 0.1\,m$

$Rs = 0.118\,m$

$Rs1 = 0.04\,m$

$Lwire = 992.743\,m$

$I = 8.058\,A$

$Resistance = 4.964\,\Omega$

Results for a superconducting Solenoid

$sB = 2.513\,T$

$sn = 50$

$sRwire = 1 \times 10^{-3}\,m$

$sk = 40$

$sLs = 0.1\,m$

$sRs = 0.118\,m$

$sRs1 = 0.04\,m$

$sLwire = 992.743\,m$

$sI = 100\,A$

the s infront of everything just means its for a superconductor

$\rho(\mathrm{Temp}) := \rho o \cdot [1 + \alpha \cdot (\mathrm{Temp} - \mathrm{Tempo})]$

$\mathrm{Temp} := 00 \cdot K, 01 \cdot K .. 300 \cdot K$

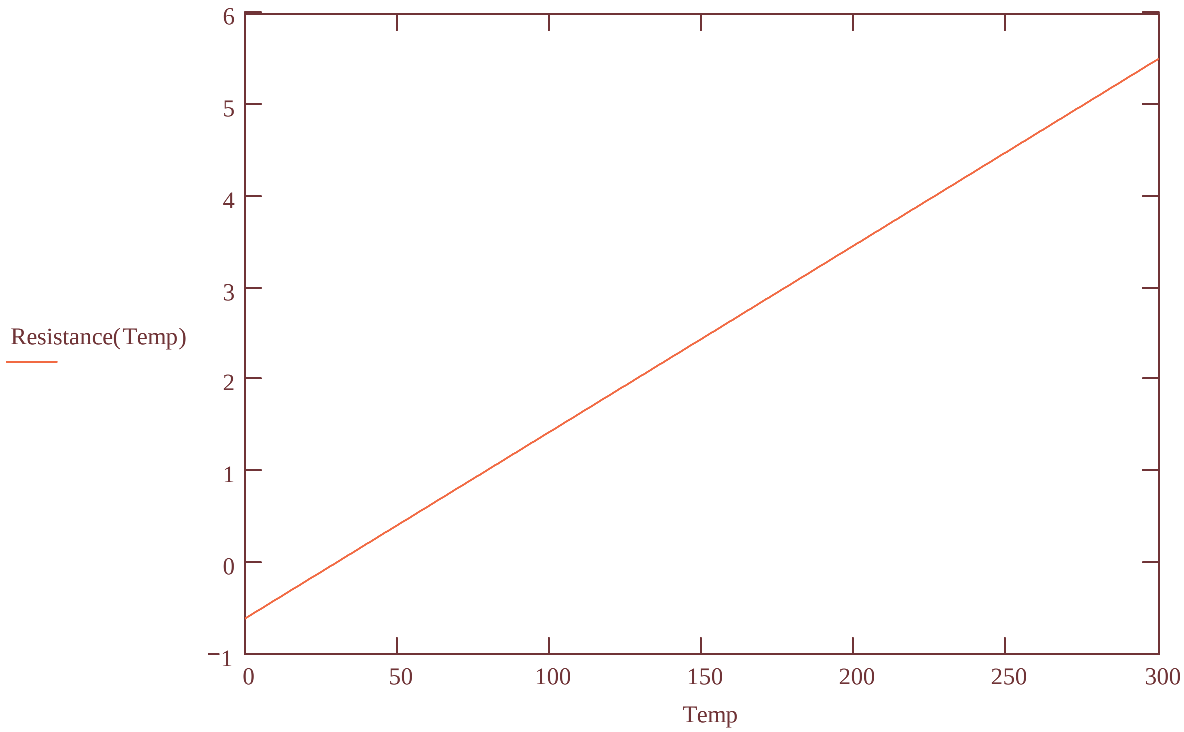
$$\mathrm{Lwire} := 2 \cdot \pi \cdot n \cdot \left(\mathrm{Rs1} \cdot k + 2 \cdot \mathrm{Rwire} \cdot \frac{k^2 - k}{2} \right)$$

$\mathrm{Rs} := \mathrm{Rs1} + (k - 1) \cdot 2 \cdot \mathrm{Rwire}$

cant have a negative resistance

$$\mathrm{Resistance}(\mathrm{Temp}) := \frac{\rho(\mathrm{Temp}) \cdot \mathrm{Lwire}}{\pi \cdot \mathrm{Rwire}^2}$$

Resistance = function



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