Fermilab Word Problems

"Bringing Fermilab to Your Classroom"

QuarkNet Teachers Workshop

Summer 2014

Objective: Our objective is to put together a document that contains word problems derived from experiments currently being done by Fermilab Scientists that can be used by teachers in the classroom.

The Dark Energy Survey

The visible universe currently observed is unexplainable without the presence of Dark Energy and Dark Matter to fill in the gaps of our current model. One would think that although matter in the universe is moving away from other matter, that because of the pull of gravity, it would eventually come back to itself. What is observed however is that the universe is expanding, and not just at a constant rate, but it is accelerating. When you drop a ball from the roof of a building, it gets faster and faster. Imagine that at a cosmic scale! Watching these astral objects move away can be misleading however. Like the doppler effect you can hear when an ice cream truck passes you, objects moving at extreme speeds also exhibit a type of light doppler effect. Use your knowledge of the doppler effect and light to answer the following questions.

1. If the light from a star is red-shifting, is it moving towards or away from the Earth?
2. What about blue shift? How do you know this?

The redshift directly gives the cosmic scale factor at the time the supernova exploded. This cosmic scale factor tells someone what the size of the universe was at the time the supernova exploded compared to what it is presently. For example, if your cosmic scale factor is $a(t) = \frac{1}{2}$, then at the time that supernova exploded, the universe was ½ of its present size.

1. During an observation, a scientist finds that light from a specific star gives a red-shift value of $z=0.5$. To get cosmic scale factor, you can use the equation $a(t) = 1 / (1+z)$. How big was the universe then compared to what it is now?

To determine the distances to these stars, cosmologists use the fact that Type Ia supernovae are nearly "standard candles": exploding stars of this type all have nearly the same absolute brightness or luminosity when they reach their brightest phase. By comparing the apparent brightness of two supernovae, we can thus determine their relative distances. This is similar to using the apparent brightness of a car's headlights at night to estimate how far away it is: if one car's headlights appear four times brighter than another identical car's, then the first car must be half the distance to the second. Type Ia supernovae are the cosmic equivalent of cars with the same wattage of headlights.

1. If a star A appears 9 times as bright as star B, how does star B's distance relate to star A's?

Just as Type Ia supernovae provide a standard candle for determining cosmic distances, patterns in the distribution of distant galaxies provide a "standard ruler". Imagine dropping a pebble into a pond on a windless day. A circular wave travels outward on the surface. Now imagine the pond suddenly freezing, fixing these small ripples in the surface of the ice.

In an analogous fashion, approximately 370,000 years after the Big Bang, electrons and protons combined to form neutral hydrogen, "freezing" in place acoustic pressure waves that had been created when the universe first began to form structure. These pressure waves are called baryon acoustic oscillations (BAO) and the distance they have traveled is known as the sound horizon. This distance is just the speed of sound times the age of the universe when they froze.

1. If the age of the universe at the time the particle froze was 10 billion years old, how far away is the particle?

Want more information?
https://www.darkenergysurvey.org/

*from Astrophysics (SDSS?)

In optics, **radiometry** is a set of techniques for measuring electromagnetic radiation, including visible light. Radiometric techniques characterize the distribution of the radiation's power in space, as opposed to photometric techniques, which characterize the light's interaction with the human eye. Radiometry is distinct from quantum techniques such as photon counting.

Radiometry is important in astronomy, especially radio astronomy, and plays a significant role in Earth remote sensing. The measurement techniques categorized as *radiometry* in optics are called *photometry* in some astronomical applications, contrary to the optics usage of the term.

In astronomy, **luminosity** is the total amount of energy emitted by a star, galaxy, or other astronomical object per unit time.[1] It is related to brightness, which is the luminosity of an object in a given spectral region.[1]

In SI units luminosity is measured in joules per second or watts. Values for luminosity are often given in terms of the luminosity of the Sun, which has a total power output of 3.846×10^{26} W.[2] The symbol for solar luminosity is $L_{\odot}$. Luminosity can also be given in terms of magnitude.

A star's luminosity can be determined from two stellar characteristics: size and effective temperature.[3] The former is typically represented in terms of solar radii, $R_{\odot}$, while the latter is represented in kelvins, but in most cases neither can be measured directly. To determine a star's radius, two other metrics are needed: the star's angular diameter and its distance from Earth, often calculated using parallax.
In the current system of stellar classification, stars are grouped according to temperature, with the massive, very young and energetic Class O stars boasting temperatures in excess of 30,000 K while the less massive, typically older Class M stars exhibit temperatures less than 3,500 K. Because luminosity is proportional to temperature to the fourth power, the large variation in stellar temperatures produces an even vaster variation in stellar luminosity.
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In photometry, **luminous flux** or **luminous power** is the measure of the perceived power of light. It differs from radiant flux, the measure of the total power of electromagnetic radiation (including infrared, ultraviolet, and visible light), in that luminous flux is adjusted to reflect the varying sensitivity of the human eye to different wavelengths of light.
The SI unit of luminous flux is the lumen (lm). One lumen is defined as the luminous flux of light produced by a light source that emits one candela of luminous intensity over a solid angle of one steradian. In other systems of units, luminous flux may have units of power.

Luminous flux	Φ_v [nb 2]	lumen (= cd□sr)	lm	J [nb 3]	also called *luminous power*
Luminous intensity	I_v	candela (= lm/sr)	cd	J [nb 3]	an SI base unit, luminous flux per unit solid angle
Illuminance	E_v	lux (= lm/m^2)	lx	L^{-2}□J	used for light incident on a surface
Luminous efficacy	η [nb 2]	lumen per watt	lm/W	M^{-1}□L^{-2}□T^3□J	ratio of luminous flux to radiant flux
Radiant flux	Φ_e[nb 2]	watt	W *or* J/s	M□L^2□T^{-3}	radiant energy per unit time, also called *radiant power*.
Radiant intensity	I_e	watt per steradian	W□sr^{-1}	**M**□$\mathbf{L}^2$□$\mathbf{T}^{-3}$	power per unit solid angle.

* more from AstroPhysics

> The atmosphere on Venus is corrosive and dense. The atmospheric pressure can be 70 times greater than on earth. In order to test an instrument for use on the surface of Venus, how deep in the ocean (on earth) would we need to go to simulate this pressure?

The Tevatron was the second most powerful proton-antiproton accelerator in the world before it shut down on Sept. 29, 2011. It accelerated beams of protons and antiprotons to 99.999954 percent of the speed of light around a four-mile circumference.

Tevatron = 3.9 miles (6.3km) in circumference

1. The average size of a *Tevatron magnet is 1.5 feet long(need to figure out actual length)*. How many magnets would you need to match the length of the Tevatron?
2. The Large Hadron Collider is 27 km in circumference. How many times bigger is it than the Tevatron?
3. Scientists often need to make rounds to check on certain components of the Tevatron. If we assume the average speed a scientist can go (legally) in a car is 40mph, how long would it take to circle the Tevatron? What about the LHC?

Want more information about the Tevatron?
http://www.fnal.gov/pub/tevatron/tevatron-accelerator.html

How about the LHC?
http://home.web.cern.ch/topics/large-hadron-collider

SciBar Booster Neutrino Experiment (SciBooNE), is a neutrino experiment located at the Fermi National Accelerator Laboratory (Fermilab) in the USA. SciBooNE was designed to make precise measurements of neutrino and antineutrino cross-sections on carbon and iron nuclei. Neutrinos, because of their neutral charge and extremely (point-like) size rarely interact with matter and travel nearly the speed of light.

1. The target site (in Minnesota) for the neutrino beam is 455 miles from the Fermilab site. About how long does it take for a single Neutrino to travel from Fermilab to the target site in Minnesota?

2. From a beam of 10 million protons, the following amount of Neutrinos are expected to be created per square meter of detector located 10 meters away:

Electron Neutrinos: 3,657 Events / $4m^2$
Electron Anti-Neutrinos: 5 Events / $4m^2$
Muon Neutrinos: 3,458 Events / $4m^2$
Muon Anti-Neutrinos: 3,567 Events / $4m^2$

2a. What percent of each type of Neutrino is created by the proton beam.

2b. Usually, a larger amount of proton beams are used. Using these percentages, how many of each type of Neutrino will be created from a beam of $1x10^{1}$□ protons?

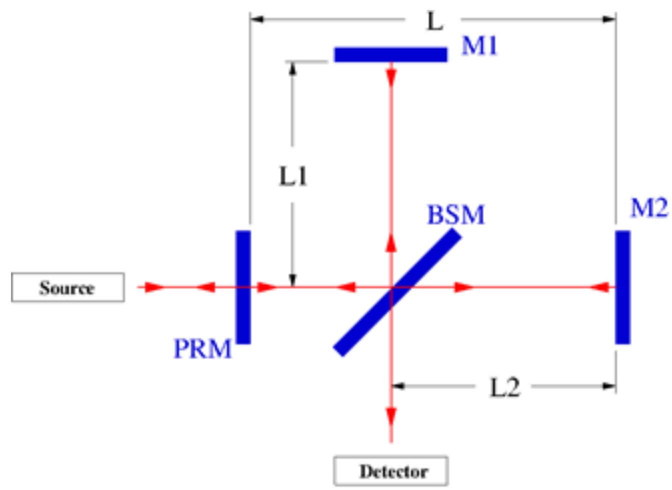
*from the Fermilab Holometer

> The Fermilab Holometer measures properties of space and time at the very smallest scales. **How small? The "Planck" length 10^{-35} meters.**

a. How many nanometers is that?
b. How many centimeters is that?
c. How many inches is that?

> The Fermilab Holometer makes measurements at a rate of 100 MHz.
How much is the time between each measurement?

The Fermilab Holometer uses a solid state laser that produces infrared light with a wavelength of 1064 nanometers.
>What is the frequency of these light waves?



The Fermilab Holometer measures properties of space and time at the very smallest scales. The experiment is testing a new idea that positions (and time) are not precisely defined. When you measure the location of an object in two directions at the same time, the measurements have extra jitter. The experiment is seeking to measure a possible very slight random wandering of transverse position. This "holographic noise" could be caused by a new quantum uncertainty of space-time. Holographic noise is purely "white noise": it has the same amplitude at all frequencies.

>What is the frequency of the Holographic Noise at the Fermilab Holometer experiment.

answer f = c / 2L = 3 x 10^8 m/s / 2 * 40 m = 3750000 Hz or 3.75 MHz *from Fermilab Computing

USQCD is a collaboration of US scientists developing and using large-scale computers for calculations in lattice quantum chromodynamics. Lattice QCD calculations allow us to understand the results of particle and nuclear physics experiments in terms of QCD, the theory of quarks and gluons.

Research and development work on commodity clusters has been carried out under the Lattice QCD SciDAC grant at FNAL and JLab. This has led to the terascale resources for lattice QCD that have been deployed at the two labs

Over the past twelve years, a wide range of processors and communications systems has been evaluated, and both switched and mesh communications systems have been studied. Myrinet and InfiniBand fabrics have been tested for switched clusters, and gigabit ethernet has been used for the mesh ones. Current clusters are all based on Infiniband, with the most recent clusters at JLab and FNAL including GPU acceleration. The conventional (non-GPU) clusters provide in 2012 a total throughput of approximately 40 Teraflop/s on lattice QCD production code. (This is the equivalent of 140 to 180 TFlops in terms of the Linpack benchmarks.)

GPU-accelerated clusters at JLab and FNAL provide a total of 620 NVidia Fermi-class GPUs. Ds, the latest conventional cluster built at FNAL, consists of 421 nodes with 2.0 GHz quad CPU eight core Opterons with a QDR Infiniband fabric, sustaining 21.5 TFlops on lattice QCD code. This cluster is shown at the right.

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*from Cosmic Ray detectors

The Pierre Auger Cosmic Ray Observatory is studying ultra-high energy cosmic rays, the most energetic and rarest of particles in the universe. When these particles strike the earth's atmosphere, they produce extensive air showers made of billions of secondary particles. While much progress has been made in nearly a century of research in understanding cosmic rays with low to moderate energies, those with extremely high energies remain mysterious.

*from D0/Tevatron/CDF

The DØ Experiment consists of a worldwide collaboration of scientists conducting research on the fundamental nature of matter. The experiment is located at the world's premier high-energy accelerator, the Tevatron Collider, at the Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois, USA. The research is focused on precise studies of interactions of protons and antiprotons at the highest available energies. It involves an intense search for subatomic clues that reveal the character of the building blocks of the universe.

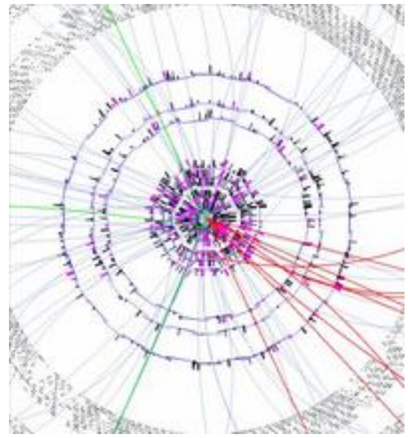
One of the most fundamental questions addressed by particle physicists today is the origin of mass. Theory holds that particles acquire mass by interacting with a field which permeates space. Within this theory an unstable massive particle, called the Higgs boson, is associated with this field. The theory predicts all the different parameters of the Higgs boson depending on its mass which is the only unknown quantity of the Higgs particle. If the Higgs boson exists, it can be produced in particle collisions at the Tevatron.

> If the mass of the Higgs particle is in the range of 135 to 200 GeV, it will predominantly decay to W boson pairs. W bosons cannot be observed directly with the DØ detector, because after their production they decay immediately into other particles.

Convert this range to grams.

> A proton circles around the Tevatron tunnel at relativistic speeds—99.999% of the speed of light. It takes just twenty millionths of a second to travel once around the Tevatron ring.
How far did it go?

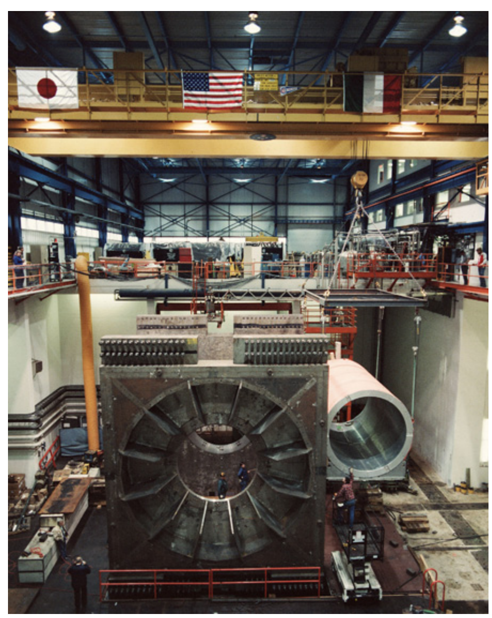
When a proton collides with an antiproton their mass, along with the energy stored in them due to their tremendous speed, turns the proton and the antiproton into a spray of daughter particles that scatter in all directions. The three-story-tall detector at CDF is designed to catch these particles, measuring their energies and in some cases tracing the paths they make as they move through the detector.



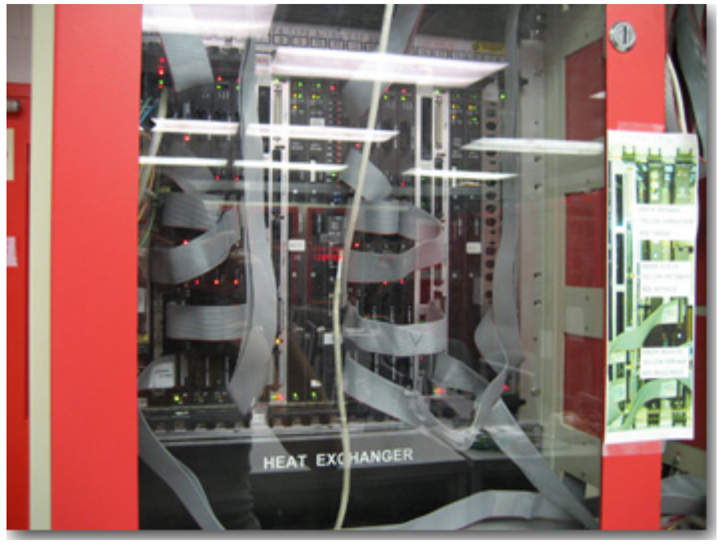
>The strength of a magnet is limited by the amount of heat generated as the current flows through it. Coils that have a high resistance — meaning they produce a lot of heat — make poor magnets; in extreme cases, the coils can heat up until they melt. Superconducting materials allow current to flow with no resistance (heat loss), but only if they are kept very cold. The cooler you keep the magnet, the more efficiently it conducts electric current.

It takes a very strong magnet to bend the paths of high-energy particles. To achieve this, scientists designed the solenoid to be a superconducting magnet, one which is cooled using liquid helium to get it down to a temperature just 4.7 degrees above absolute zero (about -459 degrees F).
What is this temperature in Celcius?

The CDF solenoid (white tube at right) waiting to be inserted into the metal shell of the CDF detector. The magnetic field is created by running an electrical current of almost 5000 Amperes (about 2500 times the current that flows through your computer) through a coil of superconducting wire wrapped around the large metal tube that makes up the body of the magnet. When the magnet is turned on, it pulls each side of the detector with a force of over 600 tons.
> Convert this force to Newtons.



There is no way physicists can sift through the three million events that take place every second inside the CDF detector. Nor should they really need to; most of these events will give them no new information about the particles that make up our universe. To weed out the boring events from the few that might contain evidence of new physics, or new information about the Standard Model particles, physicists at CDF have created a “trigger system” that uses software, computers, and high-speed electronics to pick out the events that are most likely to contain these rare processes.



> Of the three million events being produced per second, only about 150 make it through all three levels of the trigger system.
What percentage is this?

*from Fermilab Safety and Environmental

The maximum contaminant level for tritium in drinking water as given in the National Interim Primary Drinking Water Regulations (NIPDWR) is 20,000 pCi/l. The NIPDWR list a required detection limit for tritium in drinking water of 1000 pCi/l or 1 pCi/ml, meaning that drinking water supplies, where required, should be monitored for tritium at a sensitivity of 1 pCi/ml.

> During the procedure, before conducting the distillation, 0.5g sodium hydroxide and 0.1g potassium permanganate to a 100-ml aliquot of the sample in a 250-ml distillation flask.
What is the concentration (M) of sodium hydroxide?

> After discarding the first 10 mL of distillate, 4 ml of the distillate are mixed with 16 ml of the dioxane liquid scintillator.
If the distillate had a level of 200 pCi/L before this mixture, what would the level be after it was mixed?

> In the International System of units (SI), the becquerel (Bq) is the unit of radioactivity. One Bq is 1 disintegration per second (dps). One curie is 37 billion Bq. Since the Bq represents such a small amount, you are likely to see a prefix used with Bq, as shown below:

- 1 MBq (27 microcuries)
- 1 GBq (27 millicuries)
- 37 GBq (1 curie)
- 1 TBq (27 curies)

Convert the detection limit for drinking water of 1000 pCi/L to Becquerels?

> Tritium has a half life of 12.3 years. To what level would a 1000 pCi/L decay after 37 years?

*from Fermilab Detector

You need to design a detector… (computation and modeling stuff)

Below is an example of the structure of the code. The numbers after the first 3 variables represent the dimensions of the cylinder. The numbers are listed in milimeters (however in code we rarely ever write units. They are usually assumed). The material is gold (AU) and the color is represented by a red, green, blue color code. This cylinder will be composed of gold yet have a blue color. The coordinates listed assume the center of the cylinder start at 0,0,0. This one specifically is located 2.7 meters above the z -axis.

tubs Cylinder1 length=1000 innerRadius=250 outerRadius=500 material=Au color=0,0,1
place Cylinder1 x=0 y=0 z=2700

>Design the detector below so that it is 1.5 meters long, has a 0.75 m radius, is green, and is placed 1 meter above the y axis.

virtualdetector VD1 length= radius= material=Vacuum color=
place VD1 x= y= z=

>If 10,000 collision events happen in 3 minutes, how many events happen per second?

*from Neutrinos

The electroweak radius of a neutrino is represented by n x 10^-33 cm^2 where n = 3.2 for an electron neutrino, 1.7 for a muon neutrino, and 1.0 for a tau neutrino.The electroweak radius essentially means the radius that the neutrino seems to exhibit but is not necessarily the actual radius. However, for the pure sake of curiosity, we can use this as a radius and assume the neutrino is a spherical particle.

> What is the equation for the volume of a sphere?

>What is the calculated volume the three types of neutrinos?

Using the electroweak radius, how many of each type of neutrino would fit in the...

>The head of a needle?

>The sears tower?

>The earth?

>The sun?

>Milky Way?

>Are there more neutrinos in the sears tower or more Sears Tower's in the Milky Way?

*Links of interest

http://fnal.gov

http://quarknet.fnal.gov/fnal-uc/index.shtml

http://www.smarterthanthat.com/physics/physics-dont-panic-10-steps-to-solving-most-physics-problems/

http://htwins.net/scale2/

* from the Pendulum--tevatron

The primary instrument in E877 was a 50 m long, high finesse Fabry Perot Interferometer passing through two SSC Dipole Magnets operating at 6 T. The goal was to make the first measurement of the magnetically induced birefringence of the vacuum and to a precision of 0.1% a set stringent limits on Axion production. The experiment was essentially operational at E4-R in 2004.

In the development of the detector, vibration isolation mechanical systems and vibration suppression electronic feedback systems, this 23 kg aluminum cylinder, supported in a marble frame, having a resonant frequency of 0.96 Hz excellent high frequency suppression, was used many times. If you watch the pendulum carefully you can see it move when the High Rise elevators stop at each floor.

> What is the volume of the cylinder?

> What is the period of the resonant wave?

> What is the force on an individual proton in this magnetic field?

* from the MicroBOONE experiment

The MicroBooNE detector – a 30-ton, 40-foot-long cylindrical metal tank designed to detect ghostly particles called neutrinos – was carefully transported by truck across the U.S. Department of Energy's Fermilab site, from the warehouse building it was constructed in to the experimental hall three miles away.

The massive detector was then hoisted up with a crane, lowered through the open roof of the building and placed into its permanent home, directly in the path of Fermilab's beam of neutrinos. There it will become the centerpiece of the MicroBooNE experiment, which will study those elusive particles to crack several big mysteries of the universe.

The MicroBooNE detector has been under construction for nearly two years. The tank contains a 32-foot-long "time projection chamber," the largest ever built in the United States, equipped with 8,256 delicate gilded wires, which took the MicroBooNE team two months to attach by hand. This machine will allow scientists to further study the properties of neutrinos, particles that may hold the key to understanding many unexplained mysteries of the universe.

The MicroBooNE detector will now be filled with 170 tons of liquid argon, a heavy liquid that will release charged particles when neutrinos interact with it. The detector's three layers of wires will then capture pictures of these interactions at different points in time and send that information to the experiment's computers.

> What is the mass of the MicroBOONE detector in kg? Metric Tonnes?

> What is the length of the "time projection chamber" in meters?

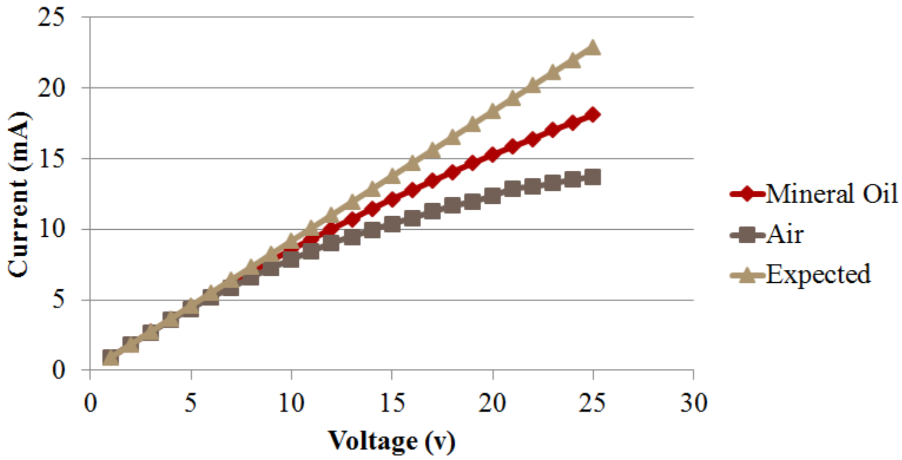
> What is the mass of the liquid Argon in kg? in metric tonnes?

> How cold is the liquid Argon? units?
> What volume would it occupy at STP?

> Under experimental conditions, what if the volume that the liquid Argon occupies ???

Ohm's Law and Measuring the Liquid Argon level of a Cannister

One of our students did an experiment using a Temperature sensitive Resistor called the PT-1000. This resistor increases its resistance as temperature increases linearly. However the relationship changes when placed in a liquid as contrasted to when it is placed in air at room temperature.



Looking at the graph above, we can see how sensitive the PT-1000 is to changes in pressure. These graphs were made by testing the PT-1000 at room temperature. Since the Air and Mineral Oil lines did not follow the expected value, this means the resistance of the PT-1000 changed as time went on. Since it only changes when the temperature changes, that tells us the temperature of the resistor changed.

1. Why do you think the temperature of the resistor changed during the experiment as time went on?

2. Using the knowledge that Ohm's Law is V= I*R, what was the resistance of the resistor?

3. About what was the resistance of the resistor at the end of each trial for the Air, Mineral Oil, and the Theoretical?

4. Why do you think the experimenter used Mineral Oil rather than water when choosing a liquid to test the resistor in?

Using the graph above, scientists wanted to make a liquid level monitor. Inside a contained, pressurized unit, once the liquid dropped below a PT-1000, the resistance would then begin following a different curve, allowing the scientists to approximately see how high the liquid is. This however did not work because of the extreme pressures in the container they were using.