Fellow Woodworkers,

I stumbled upon the following article about the use of PVC tubing (sewer pipe) for dust collection conduits. It's very well written by a well educated fellow woodworker, Rod Cole. As you will read shortly, the article is dated May 3, 2000 and for this reason, we have turned it into this pdf file, giving full credit to Rob. His research into this subject is well appreciated and after reading it, you too will be enlightened about dust collection safety and the use of PVC tubing in your workshop.

This link will take you to the actual article as last checked:
http://home.comcast.net/~rodec/woodworking/articles/DC_myths.html

Steve
Workshop Supply

Grounding PVC and Other Dust Collection Myths

May 3, 2000
Revised slightly, November 20, 2001 (edits in the Summary and Recommendations are in red)

I think more has been written on this topic on the various Web woodworking boards than whether Delta, Jet, or Grizzly has the best table saw for the money! More self proclaimed experts post more bizarre theories than at UFO conventions. I tried to be clear on what points I know or strongly believe to be true, and what points are conjecture, and what is fact and what is opinion. I've kept the hard core theory and math down, but will include a little just so you know I thought about this at some depth, not just in some vague way. Where I have them, I include citations to the appropriate literature.

I started out to write some notes on the electrical theory behind the attempts to ground PVC. I read so many posts that were so clearly wrong that I decided I had to respond. Then I decided to go to the library and learn a little about Electro Static Discharge (ESD) and the hazards of dust explosions. You will find all three topics covered in these notes. I would like to point out that I do not claim to be an expert on dust explosion hazards. I am merely reporting what I have read, in books and research journals, not the web, on the topic. If you are concerned about my representation of what I have read, I urge you to go to a good library and read the references listed at the bottom of this article, and I urge you to find additional information until you are personally satisfied with your knowledge. The notes on what is behind the so called grounding of PVC are my opinions, although they are based on known physics; they have not been verified by testing.

If anyone feels that some point needs clarification or is just wrong or has something to add, feel free to let me know. I'm ready to learn more.

These notes are organized into the sections listed below. The Summary and Conclusions section is just that, and does not include much technical material. If I stopped there, this would be no more than the usual forum post; it would be one more in a long list of "He said, She said" posts on the subject, and would have little value. For this reason, lots of technical explanation follows the Summary and Conclusions section. I suspect few people will read the follow-up sections, but they are included for those few who are interested, and to prove there is more here than just my opinion.

Who am I?

My name is Rod Cole, and I work at MIT Lincoln Laboratory heading some research projects in automated weather detection, prediction, and warning systems. This is very small scale weather stuff, not what is the weather going to be like this weekend. More like: Is that aircraft that is trying to land going to hit a microburst and crash? My work primarily revolves around mathematical data analysis algorithms of one form or another. I have a Ph.D. in Mathematics from the University of Colorado (1990) and a BS in Physics from Va. Tech. (1980). Most of my graduate work in math was highly abstract nonsense stuff, but after seeing my friends ahead of me unemployed, I got a job as a student programmer and wrote an applied thesis. So far so good on the credentials, but I feel compelled to point out that I am not a physicist or even an electrical engineer, and also that while Lincoln is no slouch of a place, I should not be confused with a professor at MIT. In writing these notes I did get some help from a friend who is a professor at MIT, who works just down the hall, and who is an expert on the physics of lightning. I have also gone to the library and perused several book on electromagnetic theory and electrostatics, books on Grounding and Shielding electronics, and about a dozen scientific papers. Interestingly enough, static charging and static discharge are not fully understood topics, and remain areas of active research.

Summary and Recommendations

Before getting started on what may at first sound very scary, I would like to point out that I have read more than a dozen research papers on this topic recently. The thing

I am most struck by is how hard these guys have to work to get dust explosions in the lab. It is not hard to get ignition if one makes a very carefully controlled, nonmoving cloud with just the right dust mix, and introduces a spark from a very carefully designed sparking mechanism. But no one seems to be able in lab sized experiments to get electrostatic discharge ignition of even very highly combustible dusts in remotely realistic situations, and they do try. Is is possible? I presume so, but it is extremely difficult. The issue, in a nut shell, is that with a charged conductor the charge is free to move, and thus the charges throughout the conductor can can join forces to make a strong spark. But, because charge on an insulator is not free to move, discharges only occur from a small area, leaving the majority of the charge behind. For this reason discharges from insulators are not as energetic as those from conductors. Glor (1988) points out in a physics journal that while there are often multiple possible ignition sources, electrostatic discharge is often given as the ignition source for dust explosions even when there is no real evidence, simply because it is hard to know what really happened.

Also, there has never, to my knowledge, been a documented case of an explosion problem with PVC in the home shop or a case of an explosion in a filter bag in a home shop. A friend of mine who is a professional cabinet maker asked his fire inspector what he thought about the hazard of PVC ducts, and the fire inspector said he was far more concerned about people keeping lighter fluid under the kitchen sink. The fire inspector was intrigued and checked whatever registry of fire information he had available and came back and said he could not find one reference to a problem in a small shop with PVC ducts. In all the years that this has been debated on the Web, not one verifiable report has surfaced of an exploding home shop dust collector. I know full well that anecdotal evidence does not make good science, and just because I don't know of a problem caused by an electrical discharge in a home shop DC does not make it impossible. But, such evidence is certainly food for thought, and at least shows that such events, if they exist at all, are very rare.

There are three distinct hazards associated with dust collection systems: the dust pile, the filter bags or cyclone, and the duct work. That each of these is a hazard is confirmed by the Uniform Building Code, Uniform Mechanical Code, and the National Fire Protection Association which (according to OSHA, 1997) all require that dust bins, dust bags, and cyclones be located outdoors, and ducts must have explosive vents to the outside. Few if any home shop systems meet these requirements. The NFPA codes, which I do have, call for grounded metal ducts. I don't have copies of all the other codes, but I have to believe that they all also call for grounded metal duct work. Also, I think it is important to note that the NFPA codes only apply to systems that move 1500 CFM or greater. Despite advertising claims, none of the systems generally available for home use, when hooked to ducts and run with filters come close to 1500 CFM. As I see it, the hazards in decreasing order of concern are: (worst) the dust bin, the dust bag, the ducts.

1. Perhaps the greatest danger in home shop dust collecting is the pile of dust itself. A real concern is mineral sparks, for example due to a blade or sander hitting metal, that get sucked up and land in the dust collection bin. This type of spark or ember can smolder for hours before a fire erupts. I know of two fires due almost certainly to such sparks. In one a floor sander bag went up in the middle of the night burning a house to the ground one town over from here. This occurred long after the sander was left sitting unemptied, and was written up in the local paper. The other was a small fire in a table saw at the Lexington (MA) Woodworker's Guild when the dust shroud was bent and hit the blade. There appear to be plenty of reports of this hazard.

2. Your dust collection bags concentrate very fine dust by letting the coarse particles drop out, keeping the fine dust suspended. A typical bag set-up, 20 inches in diameter and 6 ft high, contains 13 cubic feet of dust-air mixture, which is a significant volume should ignition occur. Filter bags concentrate fine dust, and keep it suspended due to the in-rushing air, making it more likely that the minimum dust density for ignition exists in filter bags than in ducts (the minimum dust density is about one half an ounce of dust dispersed a 13 cubic foot bag). The dust blowing around charges the bag just as it charges PVC ducts, hence an electric discharge from the bag is possible. The dust is charged (whether the ducts are metal or PVC, grounded or not) and the concentration of dust also concentrates the space charge due to the dust cloud, making an electrical discharge within the dust cloud a possibility. Also, in very large dust piles, the charge in the pile of dust can give rise to discharges along the surface of the pile. Fortunately, while electrical discharges are to be expected in filter bags, research shows that due to the small scale of home shop dust collection bags, the discharges will not have enough energy to ignite dust. If there is any significant explosion hazard from filter bags in the home shop, it is more likely to come from some improbable mishap where the bag is ignited from the outside, rather than from an electrostatic discharge.

3. The ducts are the primary concern in web forum discussions, but they are the least of your worries. To begin with, the volume of the dust-air mixture in 20 ft of 4 inch duct is 1.7 cubic feet, or equal to a cube 14 inches on a side. This is a considerably smaller amount of fuel-air mix than in a filter bag. While up and running, one pound or more of fine dust per minute must be generated with a 500 CFM dust collector to maintain the minimum dust density that might possibly ignite in the duct, or more than two pounds per minute of fine dust with a 1000 CFM DC. This is more fine dust than most home shops can generate on a continuous basis. You can get this rate of dust for brief periods if you use your DC to vacuum up a pile

of dust.

It is much harder to get a discharge inside an ungrounded PVC duct than outside the duct. Indeed, for an infinitely long uniformly charged duct, the electric field in the duct from the static is zero; no matter how much static is built up it is impossible to get a discharge in this ideal duct. In practice it is possible to get discharges in a PVC duct, especially where it starts, ends, or where dust blasts the walls such as at a T connection. The important thing is that just because you can get a nasty shock to your finger does not mean you can get a discharge in the duct. It is also possible to get discharges from the dust cloud itself (dust charges in grounded metal ducts as well as in PVC ducts), although it is very much less likely than in the filter bags since the dust does not charge for as long as in the filter bag, and because the smaller the radius the greater the difficulty in generating a discharge in the dust cloud. Fortunately, with one exception, research shows that the types of static discharge that occur in PVC ducts are not energetic enough to ignite dust. The exception is that a non conducting duct backed with a conductor, in very special circumstances, can generate static discharges with enough energy to ignite dust. While very unlikely in the home shop, this type of discharge causes me to caution against wrapping PVC ducts in grounded wire or foil.

Before the recommendations, I would like to point out a few things. Rubbing an insulating dust against the pipe wall charges the dust. There is nothing special about PVC in this regard. Rubbing wood dust against metal will do the same thing. If you have ever cut PVC with your miter saw (with its grounded metal blade) you understand just how charged an insulating material can become due to rubbing against a grounded conductor. The point of metal ducts is not that they will not charge the dust, because they will. The point of metal ducts is also not that they will remove charge from the dust cloud. The dust cloud itself is insulating; it can not be grounded. Similarly, the point of grounding attempts with PVC is not to remove charge from the dust. This is the most common fallacy in discussions regarding grounding. Grounded metal ducts are used because discharges from metal to metal are often energetic enough to ignite dusts, and grounding prevents discharges from the ducts to other grounded items. Discharges from within the dust cloud are possible in grounded metal containers. In fact, explosions occur due to discharges in charged clouds in super-tankers on occasion, and super-tankers are grounded metal containers. Fortunately that is not a concern for us due to the small size of the ducts. The reason PVC is banned is because when backed with a conductor (or otherwise is highly charged on the outside as well as inside), and very special circumstances occur, a discharge with enough energy to ignite dust may occur.

I would also like to point out that you can not truly ground PVC; there is nothing you can do that will guarantee that a static discharge from the duct will not occur. While you can not actually ground PVC, the so called “grounding” seems to help anyway according to many accounts. Typically people add so called “grounding” using one or more of the following: a grounded wire inside the duct work, a grounded wire wrapped around the outside of the duct, or by having grounded screws poking though to the inside of the pipe. Interestingly enough, I’ve never heard of anyone wrapping grounded aluminum foil around the ducts, which for 4 inch PVC costs about 2.5 cents per lineal foot, or about a dollar to do 40 feet of ducts. Wrapping the ducts in foil will make your attempts at “grounding” much better than simply wrapping in wire. However, as discussed above, backing a PVC duct with a conductor is problematic. At least three effects may play a role in the so called “grounding”: leakage currents and shielding for outside wires, and providing a short hop to ground for inside wires or grounded screws through the pipe wall. Leakage currents and the short hop to ground work to reduce charge build up. Shielding works to protect you from a discharge to your body, but does not reduce charge in the pipe. The effectiveness of the attempt at “grounding” will depend on many factors, and may be overwhelmed if the system is pushed too hard.

Recommendations in order of importance:

1. Codes call for keeping the collected dust outside, but this is not feasible in most home shops. However, while small, the risk of fire in the collected dust is real. I recommend that you empty the dust each day, or at least keep the dust in a sealed metal container. This is not hard to do if you use a cyclone that empties into a metal can that you can cover with a metal lid, or empties into a trash can lined with a plastic bag.

2. Codes call for keeping filter bags and cyclones outside, but again this is not feasible in most home shops. Buying low (electrical) resistance bag with explosive vents is also not feasible. However, due to the small size of home shop filter bags, the risk of explosion is extremely small. The risk in a cyclone is much smaller than for a filter bag. If you wish to protect yourself from the electrostatic discharge hazard in filter bags the easiest thing is to use a metal cyclone with a metal bin, and ground everything metal.

3. Codes call for grounded metal ducts, which are feasible in the home shop. They also call for explosive venting to the outside, which is not generally feasible. However, if you choose to use PVC ducting in your home shop, the risk of an electrostatic explosion due to the ducts is, at worst, extraordinarily small. From the research papers I have read, this risk is essentially zero, and is much less than the risk due to items 1 and 2 above.

If you use PVC the primary issue is to protect yourself from a shock. For this I recommend either a bare grounded wire in the duct, or grounded screws through the pipe spaced every 4 inches. This will reduce the maximum charge build-up by allowing more discharges at lower energies. In a four inch duct, the maximum discharge distance to the bare wire is 4 inches, and the maximum discharge distance to the ground screw is 4.5 inches, so both give approximately equal protection. Because both the wire and screw point have very small radii, they will cause discharges at a much lower charge density than you need for a similar discharge to your finger. The advantage of the screws is that they will not hang up shavings like the wire can. If you are not concerned about receiving shocks, you need not ground the PVC ducts. It is likely that the external ground wire, bare or insulated, or grounded foil wrap is safe in the home shop, but this is problematic if you can generate very large amounts of fine dust.

I think it is safe to say that the issue of exploding PVC pipes in the home shop is way over blown. I also do not think you need to fear your home shop filter bags. If you read all of this article, I think you will agree. I do think that the dust pile poses a small, but real hazard. There have been documented cases fires started by mineral sparks or embers being sucked into the collected dust. If you are serious about making your dust collection system safer, the place to start is to empty the dust every time you leave the shop or at least keep it in a closed metal container. But if you want to worry about big sparks, it is worth noting that many more houses burn down due to lightning than due to dust collection, so you may want to add lightning protection to your house. More houses burn down due to flammable liquids such as paint thinner and varnish than due to dust collection. Many many more people die from driving too fast; all sorts of things in your life are more dangerous than your dust collection system. If you sincerely want to make your life safer, there are many things you might more profitably do than worry about PVC ducts, especially ones that are already in place. On the other hand, if you are just putting in ducts, and the extra cost and trouble is of little concern, by all means put in metal ducts and ground them. Metal ducts properly grounded are the safest way to go, and frankly, HVAC ducting from the local building supply store is not expensive. If nothing else, the use of metal ducts will protect your body from discharges that can be quite painful.

Added 11/20/2001

A week after mentioning the article on the Web site Badger Pond, I noted many lunchtime readers, and added a counter. Not counting that first week, there have been over seven thousand readers, and the response has been overwhelmingly supportive. Several people have contacted me. Jim Kull and Al Stokka talked to their local Fire Marshals who knew of no fires from PVC ducts in home-shops. Rob Robertsen, Fire Marshal, and Eric McMullen, fire inspector, report no knowledge of any examples either. I heard that Oneida claimed PVC was a hazard and contacted them, but Rob Witter read the article and agreed with the conclusions. One particularly valuable safety idea, adding a low cost automatic sprinkler head over the dust collection bin, was sent by Larry Verhoff.

Discussion of Electrostatic Discharge and Dust Explosions

In order to get a dust explosion you need two things to occur simultaneously. You need the right concentration of dust and you need an energetic enough source of ignition. There is an upper and lower limit for the dust concentration, too lean or too rich and you can not get ignition. Typical values for the minimum dust concentration that can ignite are about 50 grams per cubic meter, for example for corn starch and coal dust (OSHA 1996). This translates into about 0.003 lb. per cubic foot, or in the ducts this works out to about 3 lb. of fine dust per minute for a 1000 CFM dust collector (but only about 0.3 lb of dust per minute for a 100 CFM shop vac). I have been told that according to a Bureau of Mines Report (No. 5753) that I have not read, that for white pine the minimum dust concentration is about 0.002 lb. per cubic foot, or somewhat less than the OSHA value. In addition, the dust must be very fine so that there is enough surface area.

At some point between the upper and lower limits exists the optimum mixture in that it will ignite with the minimum amount of energy. Typically, volatile gas-air mixtures ignite with minimum energies of about 0.1 mJ, while dust mixtures have minimum ignition energies in the range of about 1 m J to 100 mJ: the discharges needed to ignite dust need to be much more energetic than those that ignite gas-air mixtures (I apologize, but I did not record the reference for these values. In Schwenzfeuer and Glor (1993), they needed a very easy to ignite dust and chose finely powdered sulfur which has a minimum ignition energy of 0.8 mJ, and needs a discharge of 1.3 mJ to ignite with full reliability). As the mix becomes leaner or richer than optimal, or the dust becomes more coarse, the required energy for ignition rapidly increases, reaching a theoretical value of infinity at the upper and lower limits. For this reason, the range of mixes that might in practice ignite with an electrical discharge is much narrower than you can ignite with a flame. The values above for ignition energies are for static clouds. Moving dust is much harder to ignite as shown by Thomas and Oakley (p. 201) using explosive dust (e.g. TNT) with velocities of 14 m/s to 32 m/s (2800 ft/min to 6300 ft/min). DC speeds in 4 inch pipes are about 1000 ft/min for each 100 CFM, and in general should be at least 3500 ft/min to keep dust from settling in the ducts. Last, the ignition energies so far discussed are for powders, not a mix of chips, shavings, and powders as come off most woodworking machinery. As can be seen from this, and the discussion below on the different types of discharge, igniting wood saw dust with an electrical discharge is not an easy feat.

The following is distilled from Schwenzfeuer and Glor (1993) and Glor (1988), unless otherwise noted. There are six kinds of discharge: spark, brush, corona, propagating brush, lightning-like, and discharge from bulked powder. They occur in different environments and only some have the energy to ignite dusts even under optimal conditions. Spark discharges generally only occur between two conductors, and can not occur if all conductors are grounded. Spark discharges may ignite dusts. It is generally agreed that brush and corona discharges can not ignite dust. Discharges from or to insulators, pipe or dust cloud, are almost always brush discharges, although in special circumstances insulators can give rise to propagating brush discharges which can ignite dusts. Lightning-like discharges in the dust cloud itself can ignite dust, but do not occur in dust clouds smaller than about 3 meters (10 ft) in diameter (Boschung, et al, p. 309). Last, there can be discharges along the surface of the pile of charged dust in a bag or bin that can ignite suspended dust above the pile, but this requires at least 100 L (25 gallons of dust pile) and may in fact require a pile of about 1 cubic yard or more. As long as we stick to home shop sized equipment and all metal is grounded, there are only corona, brush, and propagating brush discharges to consider, with one exception discussed below regarding cleaning dust bags. Of these, only propagating brush discharges are an ignition hazard. To get a propagating brush discharge there must be a very high charge density on an insulator (> 2.7x10-4C/m2), a charge of opposite sign on the other side of the insulator, and a very high voltage across the insulator, 4kV for an insulator 10 micrometers thick (400 million V/m) and 8 kV for an insulator 200 micrometers thick (about 0.01 inch, and about 40 million volts per meter). Generally, plastics breakdown at less than 40 million V/m, so this is not a concern for thin plastics such as a trash bag in the dust collection bin. At an insulator thickness of about 0.3 inches it becomes impossible to get a propagating brush discharge. In our case, the only real way to generate a significant charge of opposite sign across an insulator is to put grounded metal on the outside of the PVC pipe. The authors state that the places where the insulator is blasted with dust, and thus experience a great deal of charging, are where you might get such discharges. So this is a greater hazard at elbows and T's than along straight lengths of pipe.

Other Filter Bag Issues: If all metal parts are grounded, any discharge in a filter bag is likely to be a "brush discharge" which does not have the energy to ignite the dust cloud. This discharge can be from the bag or even from within the dust cloud itself due to the space charge (Boschung, et al, p. 306). An exception is when cleaning the bag and the dust layer separates from the bag it is possible to get a "spark discharge" which does potentially have the energy to ignite a dust cloud (Ptasinshi, p.315), but the discharges Ptasinshi achieved due to dust layer separation were all less than 1.0 mJ, or outside the range for dust ignition (Ptasinshi, p. 318). One last, but extremely remote, possibility is a "propagating brush discharge", which is energetic enough to ignite a dust cloud. This requires a bag with a very high breakdown strength and with a very large charge on the inside, that somehow has also gotten a significant charge of opposite sign on the outside of the bag (Glor, p.211). The other types of discharges are ruled out due to the small size of home shop bags.

Other PVC pipe issues: Due to the size of the duct, there is no hazard due to a discharge from the space charge in the dust cloud itself; a discharge is very unlikely and if it occurs it will be a brush discharge. The non hazard due to the charge in the dust itself is noted by Glor (Glor, p.215), although Crowley points out that it is not unlikely that discharges in a pipe as small as 10 cm (8 inch diameter or 4 inch radius) can occur, (Crowley, p.43).

Some Basic Electrical Theory

Charge, Field, Voltage, and Grounding: It is well known that like charges repel each other and opposite charges attract each other. The force of attraction or repulsion is transmitted via something called the electric field. The electric field has both a magnitude (strength), and a direction. The field from a single point of charge points directly away or toward the charge and the magnitude decreases as one over the distance squared. Charge has units of coulomb and the field has units of newton/coulomb which is equivalent to volts/meter. Moving a charge against an electric field takes energy, giving rise to the notion of potential (energy) and the quantity Volts. If you move along the direction of the electric field you multiply the strength of the field by the distance traveled to get the voltage between the starting and ending points.

In a conducting solid there are an immense number of electrons that are free to move; positive charge is locked in place in the center of the atoms. In conducting liquids and gasses, there may also be positive charge that is free to move. We are only concerned with conducting solids, and when I refer to conductor, I mean a conducting solid. In a conductor the electrons arrange themselves so that they are "as far apart as possible" due to the repulsion they experience. If more electrons are added (or some taken away) the electrons again move so as to get "as far apart as possible." Thus the excess charge is spread out. If the conductor is symmetric like a sphere or infinitely long cylinder, the charge is uniformly distributed.

If there is some static charge, say extra positive charge on a PVC pipe, this charge gives rise to an electric field that attracts electrons. If a conductor is placed nearby, this field pulls some of the free electrons in the conductor to the side of the conductor nearest the charged PVC. This leaves a net positive charge on the backside of the conductor. Of course the electrons drawn toward the PVC repel each other, and are attracted to the positive charge left behind. When the force of attraction from the PVC balances with the force of repulsion from the electrons bunching up and the pull of the positive charge on the other side of the conductor, the electrons stop moving and the system is in equilibrium. In other words, inside the conductor the total electric field (the sum of the field from charge outside and the field from the charges inside) is zero and the entire conductor is at the same potential; if it were not, free electrons would feel a force and they would move. If the conductor is made larger, the same thing happens; electrons are drawn to the PVC side leaving a net positive charge on the other side. If the conductor is made as large as the Earth (that is the conductor is grounded), the positive charge vanishes into the earth and as far as what is seen in the lab, they are gone. The negative charge of course remains on the near PVC side the conductor. Even though there is a net charge on the part of the conductor that remains in the lab, the potential or voltage is constant in the conductor because the field from this remaining charge just balances the field from the nearby static charge. The charge drawn to the PVC side of the conductor increases the field outside the conductor, and the more pointed the conductor the greater the electric field. The concentration of the electric field around pointy conductors is why you tend to get sparks to your fingers, or why you get sparks to the edge of your lips or end of your nose when you go to kiss your sweetie in the winter. The strength of an electric field at some point depends on the amount of charge nearby, the distribution of the charge (the shape), and how far away the point is from the charge.

In (or on) an insulator, there are no charges that are free to move, so there is no requirement that excess charge be uniformly distributed. In an ideal insulator, charge does not move at all. In practice there are no ideal insulators or ideal conductors. The measure of how hard it is for charge to move is called resistance and has units of ohms. Charge on a typical insulator is some 100 billion billion (1 with 20 zeros) times harder to move than on a typical conductor. If an insulator is placed in a very strong electric field the electrons can literally be stripped from the insulator. This is called dielectric breakdown which gives rise to an electrostatic discharge. For plastics this occurs for electric fields of around 20 million volts per meter, and for air this occurs at about 3 million volts per meter. The larger the gap the discharge jumps, the more energy released. The primary issue in static discharge is not voltage or current. The issues are charge and charge density, and the resulting electric field, and ultimately the amount of energy released.

While the charge in an insulator is not free to move, an electric field will modify the location of the electrons. While not literally true, you can think of the electrons as little planets orbiting the protons in the atomic nucleus. (A better model is to think of the electron as a cloud with no specific location, but more or less centered on the atomic nucleus). When an insulator is placed in an electric field the electrons orbit off center, thus the atoms become something called dipoles; one side has a negative charge and the other has a positive charge, even though the electron is still tied to the atom. This has the effect of making the field in the insulator smaller than if it were in a vacuum (air is very nearly a vacuum as far as this is concerned). For typical plastics, the field is reduced by about a factor of about 3 inside the insulator. So, in order to get dielectric break down of plastic you need a field from enough charge to give a field of about 60 million volts per meter in air, or about 20 times what is need to rip apart air.

In a DC system, the dust is charged to some extent when it is generated. As the dust slides along the duct walls it can continue to charge. Charge builds up on the inner surface of the PVC pipe due to charge transfer that takes place due to the collision of wood particles with the pipe wall. In turn, the dust picks up an equal but opposite charge. When the dust has cleared the pipe the charge on the inside of the pipe remains until it bleeds off one way or another. The charge on the dust winds up in the bin or bag along with the dust. It is the field from these static charges that may give rise to the static discharge that concerns us.

The electric field in an ideal charged pipe: To warm up to the subject of electric fields, let's look what happens if we have a uniform distribution of charge on a infinitely long cylindrical shell (e.g. on the inside of a long run of PVC pipe). This is where things sit after the dust has been sucked out of the ducts. Each point of charge has an electric field that points radially outward (or inward depending on whether the charge is positive or negative). The field at any point is the sum of all the fields from the individual charges. First think about what is going on at a point at the center of the pipe. There are charges equally spaced all around the center point at a distance r (radius of the pipe), and the field lines are all pointing towards the center of the pipe (for a positive charge): they sum to zero. You can work this out mathematically, but I'm going to skip that. Consider instead the simple picture below, and you can see how this works with two charges and the points in between. In the picture it looks like the field has the same strength at all points, but that is not the case. The field strength from each charge decreases as 1/distance2, so the fields only cancel at the point half way in between for these two charges.

outside pipe   inside   outside
<-- <-- <-- (+) --> --> --> --> --> --> -->
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If we think about what happens if we move the point we are considering to the left of the center of the pipe, the field from the points on the left gets stronger since the point is now closer to those charges. But, there are now more charges on the right. It may not be obvious, but the decreasing field strength from each charge on the right is just counter balanced by the fact there are now more charges on the right! The result is that there is no electric field inside the pipe. Outside the pipe there is an electric field and it decreases as 1/distance to the center of the pipe (not 1/distance2 as if we had a charged sphere); thus the field outside the pipe is exactly the same as if all the charge was on a line in the center of the pipe. One important implication is that without dust in the duct, it is easy to get a spark outside the duct, but very difficult inside (in fact impossible in this ideal case). While we have skipped a rigorous mathematical proof, this is covered in the first chapter or two of electrical theory in every first year physics book if you decide you want to see the mathematical details. In practice, the pipes are not infinitely long and the charge is not uniform. The fields do not all cancel near the ends of the pipe or where pipes bend or join. The charge is not uniform, being stronger where dust rubs more vigorously, such as at a T connection where the dust blasts the side of the pipe.

The electric field from a volume charge: In things such as grain elevators, the primary concern is the electric field due to the cloud of charged dust. To understand the electric field at a point at some distance d from the center the pipe due to a uniformly charged dust cloud in the pipe, you can consider the cylindrical cloud of charge to be a bunch of concentric cylindrical shells and you add up the electric field from each shell to get the field for the entire volume (this is close to correct without getting into more advanced mathematics). Here we assume a uniform charge density. Remember the result just above. Inside any of these shells there is no field and outside the field strength drops off as 1/distance from the pipe center line. Thus, at any point in the pipe the electric field is the same as if all the charge closer to the center were in fact at the center, and all the charge farther from the center line did not exist. The end result is that the maximum electric field due to the dust cloud occurs at the duct wall, and is proportional to the charge density times the duct radius (Crowley, p.44) . The electric field for a spherical volume also has this form, although the proportionality constant is different. This result holds for things like dust collection bags even though the calculations get more difficult as the shapes get more complicated.

This is an important result: as the radius gets smaller, the charge density must go up in order to get a discharge in the dust cloud. The radius of the duct is on the order of 10-1 meters, the radius of a grain elevator is on the order of 10 meters, a thunder storm has a radius of perhaps 103 meters. In order to get the electric field strong enough to cause a static discharge you need a dust charge density in your ducts that is 100 times greater than needed to cause a static discharge in a grain elevator, and 10 thousand times greater than in a thunder storm. Remember that for a pipe with a uniform charge density on the wall, and filled with a cloud of uniformly charged dust, the field in the pipe is due to the cloud only. Outside the pipe both play a role, but not inside. You may be tempted to think that the smaller the duct the greater the dust density (you are packing the same amount of dust into a smaller pipe, right?) If we fix the volume of air per minute, for example we keep the same blower and we don't go to ducts so small that the blower is choked, the dust density neither increases or decreases with the size of the duct because while the dust is being drawn into a smaller volume, that volume is also emptied faster such that the density remains constant. While the charging of the dust may occur faster due to the faster air in the small duct, the residence time of the charge in the duct decreases by the same factor as the increase in air speed.

What so called "grounding" really does

First: You can't ground PVC. Despite all you might have read, you simply can not ground PVC or any other insulator (dielectric). Just for emphasis: you can not ground PVC. It is really a shame that people, even those who should know better, insist on calling adding grounded wires near PVC, grounding PVC. It isn't. Unfortunately, it is the accepted term, so I'll call it "grounding" too, but I'll put it in quotes.

Typically people add so called "grounding" using one or more of the following: a grounded wire inside the duct work, a grounded wire wrapped around the outside of the duct, or by having grounded screws poking though to the inside of the pipe. Interestingly enough, I've never heard of anyone wrapping grounded aluminum foil around the ducts, which for 4 inch PVC costs about 2.5 cents per lineal foot, or about a dollar to wrap 40 ft of duct. Wrapping the ducts in foil will make your attempts at "grounding" much better than simply wrapping in wire, as we will see below. However, it is possible with an insulator backed with a conductor to get something called a propagating brush discharge which has a higher energy than a simple brush discharge, and may ignite dust. While you can not actually ground PVC, the so called "grounding" helps anyway. At least three effects may play a role in the so called "grounding": leakage currents, shielding, and providing a short hop to ground (i.e. shorter than to your finger!). The effectiveness of an attempt at "grounding" will depend on many factors, and may be overwhelmed if the system is pushed too hard.

To demonstrate that the idea of an external wrapping of a ground wire is not crazy, consider that the American Gas Association in its February 1985 Plastic Pipe Manual for Gas Service states that "When conditions exist that a flammable gas-air mixture may be encountered and static charge may be present, such as when repairing a leak, squeezing off an open pipe, purging, making a connection, etc., arc preventing safety precautions are necessary." P. 57 urges a number of precautions, number one being the use of a grounded wet tape conductor wound around or laid in contact with the entire section of exposed pipe (OSHA 1988).

Leakage currents: Leakage currents occur because insulators are not perfect. They are very small, but will allow charge to bleed off an insulator. I'm not the first to suggest leakage currents. I remember one ugly set of posts to a bulletin board where a fellow was rudely denounced as an idiot for such a suggestion. One especially rude guy had gone home to measure leakage currents with his Radio Shack meter across the PVC wall at a point and didn't find them, so came back to laugh in this other guy's face. Well duh! That's like looking for atoms with your hand held magnifying glass and concluding atoms don't exist.

We can consider a small patch of the duct wall to be a flat plate. (To see that this approximation is valid, repeat the calculation below with a cylindrical shell of charge, then expand the resulting formula using Taylor's Theorem and consider that the wall thickness is small compared to the pipe radius. I use the flat plate approximation because it simplifies the explanation by removing the use of calculus.) Some charge is placed on the inside wall of the pipe, and a grounded conducting plate is placed on the outside of the pipe. The field from the static charge inside the pipe causes an equal but opposite charge to build on the grounded plate on the outside of the pipe. This is a little like a parallel plate capacitor, except that the charge on the inside is not free to move if connected to the outside plate. That this is not a capacitor is a good thing as a capacitor is the primary component of a cattle prod! We will see that while the movement of charge through the pipe wall is very very slow compared to what happens with a conductor, the time to discharge is perhaps smaller than the time to charge the pipe to the point that a static discharge occurs. Since the usual practice is to use loops of wire around the duct work rather than cover it with a grounded conductor, there is then a leap to the case of wrapping the pipe with a ground wire.

Let E be an electric field, SI units are newtons/coulombs which is equivalent to volts/meter.
Let V be voltage, units of volts.
Let R be resistance, units of ohms (an ohm is a volt/amp or a volt-second/coulomb).
Let Q be the charge placed on the patch inside of the pipe due to the dust, units are coulombs C.
Let I be current, units of amps (an amp is a coulomb/second), = V/R = dQ/dt where t is time in seconds.
Let A be the area of the patch, units are meters squared.
Let *s* be the permittivity of free space = 8.85×10^{-12} farads/meter (same as C/(volt-meter)).
Let *p* be the resistivity of PVC, varies between 10^9 and 10^{13} ohm-meters.
Let d be the thickness of the PVC pipe wall, in meters.
Let k be the dielectric constant for PVC, about 3.

The electric field in the pipe wall is then

$E = Q/(k\, s\, A)$,

and the voltage across the wall is

$V = Ed = Qd/(k\, s\, A)$.

The resistance of the wall is

$R = pd/A$.

So, the current

$I = V/R = Q/(k\, s\, p)$. But, the current is also, by definition, equal to the time rate of change of charge and charge is shrinking, so

$dQ/dt = -Q(t)/(k\, s\, p)$.

Thus we solve this little differential equation to get to the formula for how fast the charge is leaking across the pipe wall:

$Q(t) = Q_0 e^{-t/ksp}$.

So the charge decreases to 1/e (about 37%) of the initial charge in ker seconds. Plugging in the values above, we get the time to drop the charge to 37% of the initial charge to be between 0.03 seconds and 5 minutes, depending on the quality of the PVC. Doubling this time drops the charge to about 14% of the initial charge, three times gets the charge to 5%. The range of PVC resistivity I used came from a reference book on electrical insulation properties of various materials. I have no idea where Home Depot grade PVC might be in this range. The important thing is that if it takes running your DC several minutes to build up enough charge to create a discharge, leakage currents may bleed off charge fast enough to keep the charge build up to a safe level. Leakage currently will not keep the ducts free of charge. Clearly the possibility of over loading the leakage of charge exists. Interestingly enough, PVC resistivity goes down (a good thing here) if the humidity goes up.

One problem of course is that people are not covering their ducts in grounded conductors. They are wrapping them in loops of wire or running wire in the ducts. Clearly this affects the electric field and thus the leakage current. Calculating these effects is difficult, and I have not done so. How fast does charge bleed off due to leakage currents in your pipes in your shop? I do not know, and it will depend on things such as how far apart you space your loops of wire. Notice that this works with insulated wire as well as bare wire. The insulation on the wire is no different that making the PVC wall a hundredth of an inch or so thicker, which makes little difference. Using aluminum foil instead of loops of wire will maximize the protection due to leakage currents. In either case, the possibility of causing propagating brush discharges should be considered.

This should not be confused with dielectric breakdown. For PVC to breakdown you need a field strength of about

20 million volt/meter in the pipe wall. Because the dielectric constant of PVC is about 3, the charge needed to build a field this strong in PVC would build a field of 60 million volts/meter in air. So, in this case you would have a field some 20 times greater than needed to ionize the air just outside the pipe! Well before you got to this point your ducts would glow all by themselves!

Shielding: If you cover your PVC ducts with a grounded conductor there will be no field outside the pipe due to the charge inside the pipe, because the grounded conductor will charge to the opposite sign from the inside charge in such a way that there is no electric field at the outer side of the conductor, and thus no field outside the conductor. We could go through another little physics exercise, but this is well understood stuff. Simply consider that if in the grounded conductor there were an electric field there would be a current and it would not be in equilibrium. Considering the calculation above on leakage currents in insulators, and the fact that conductors pass current more than a billion billion (that is meant to be two of them) times more easily than insulators, we see that the system will very quickly come to equilibrium, i.e. nearly instantly there will be no current in the conductor. Thus the field in the conductor due to the static charge is counter balanced nearly instantly by charge drawn into the conductor. This effect is called shielding, and is the reason that coaxial cables are used to feed the signal to your TV. In the case of your TV the issue is to keep the stray fields outside the cable from affecting the inside, rather than our interest of keeping the field inside the pipe from affecting the outside. In either case, the field on one side does not exist on the other side of the shielding. Since there is no field outside the pipe you will not shock yourself or otherwise get a discharge there. There may well be a field inside the pipe so this does not prevent a discharge inside the pipe. To be free of the charge inside the pipe you have to wait until the charge slowly bleeds off through leakage currents in the PVC or through the air.

Again, no one is wrapping their PVC pipes with aluminum foil (at least no one I know of), so again we have the issue of only having wire loops wrapped around the pipe. Charge will move into the wire providing some shielding, but because the charge does not have complete freedom of movement, the shielding will not be complete. If the wire loops are close together the partial shielding may be enough to protect you from being shocked. Clearly windings close together are better than windings far apart, but we are left with the question of how close together the loops should be, and it would seem that whatever protection this provides could be overwhelmed under extreme conditions. Notice again that this works with insulated wire as well as bare wire. The insulation on the wire is no different than making the PVC wall a hundredth of an inch or so thicker, which makes no difference. Again, covering the pipes in grounded foil is the best way to go if shielding is the goal, giving complete shielding outside the pipe for any charge density. In either case, the possibility of causing propagating brush discharges should be considered.

The inside wire or grounded screws: Many people use a bare grounded wire inside the ducts. This may provide some amount of leakage current, but the primary effect is to provide a shorter hop to ground than if no wire is added. Since the wire has a very small radius, the field due the charge drawn into it by the static charge is large, making discharge occur at smaller charge densities than if the wire was not there. The discharge will be a brush type discharge which will not ignite the dust. This limits the amount of charge that can build up, which in turn limits the strength of the field outside the pipe where your unsuspecting finger is. Basically, this reduces the chance that your finger will become the shortest path to ground! By limiting the charge build up, this also reduces the chance of a propagating brush discharge. Grounded screws poking through the duct wall provide much the same protection. For a single wire in a 4 inch duct, the maximum discharge distance is 4 inches. The maximum discharge distance for screws placed 4 inches apart along the pipe is 4 inches across the pipe and 2 inches sideways, for a total distance of just under 4.5 inches, so the protection is about the same, and may even be better as screws have sharp points that increase the strength of the electric field leading to discharges at smaller charge densities. Because this type of grounding does not have the potential to cause a propagating brush discharge, I think this is safer than the external ground wire. Using very short screws will not cause the jamming up of shavings that often occurs with the internal ground wire.

Myths:

Here are just a few of the myths I have read regarding DC dangers and grounding PVC in particular.

1. The number one myth must be that **PVC ducts are dangerous.** As both theory and practice show, home shop DC explosions are somewhere between extraordinarily rare and nonexistent. The volume of a typical run of 4 inch duct, say 20 feet, is about 1.7 cubic feet or equal to a cube 14 inches on a side. I do not know the explosive power of this volume of dust, but I do not think this is going to level your shop.

2. The number two myth must be that **you can ground PVC**. You simply can't ground an insulator. There are things you can do to reduce the odds of a strong discharge, especially to your body, but they are far from perfect.

3. The number three myth is the unstated corollary to myth #1: **the only thing of concern in a dust collector are the ducts.** As seen above, the collected dust pile and the collection bag are greater hazards than the ducts. Fortunately, in practice home shop sized dust bags have shown themselves to pose little explosion hazard.

In no particular order:

4. **The external ground wire works by reducing the static on the outside of the PVC.** There is little or no static on the outside of the PVC unless you are rubbing the outside for some reason; the static is on the inside. The electric field due to the static charge in the pipe can cause a discharge on the outside, but this in no way means there is static on the outside. Indeed, if there were lots of static on the outside, say due to lots of charged dust floating around from poor quality filter bags, the static on the outside will be the opposite charge from the static inside since opposite charges attract each other. Thus the electric fields from the two will tend to cancel each other as discussed above in shielding. Outside static helps protect you! The charge on the external ground wire due to the electric field from the charge in the pipe will also be of the opposite sign. The outside static and the ground wire have the same sign; they repel each other! Static on the pipe is not drawn to the ground wire. There is no reduction in outside charge due to the external ground wire. And, if you believe that not enough charge will go through the pipe to be of help, how is it that the charge will go along the pipe? It is an insulator either way.

5. **The external wire must be bare**. The effectiveness of an external ground wire is not "lab tested", but if you believe that a ground wire separated from the static charge by a 1/16 of an inch to 1/8 of an inch of insulator does some good, certainly adding an additional couple hundredth of an inch of insulator on the wire is not going to make much difference. As seen in the specific proposed mechanisms above, the extra insulation does not significantly hinder the value of the external ground wire.

6. **Grounded screws can not help as they are too far apart.** The maximum distance from pipe wall to internal ground wire is the four inches across diameter of the pipe. The maximum distance from pipe wall to the screw is the square root of 42 + (spacing/2)2 or a little under 4.5 inches for a screw spacing of 4 inches. Four inches vs. four and a half inches is a very minor difference. In addition, the screw point leads to a stronger electric field since it has a smaller radius than the wire, so in fact the screws may well work better than the internal wire.

7. **Grounding works by removing charge from the dust.** The dust is an insulator just as the PVC is. The dust is in contact with the grounding for only a fraction of a second, even in a metal pipe. You will remove very little charge from the dust.

8. **Metal ducts keep the dust from charging.** Dust charges perfectly well in metal ducts. Grounding metal ducts keeps the ducts at an equal potential so you don't get metal to metal sparks. Further, to the extent that you are grounded, you won't get a spark to your body either.

9. **Any spark will ignite the right dust mixture.** Dusts are much harder to ignite than gas mixtures. Electrostatic discharges come in many varieties, and only a few will ignite even the most easily ignited dust mixtures. It is very unlikely that you can generate a discharge strong enough to ignite the perfect dust mixture; this pretty much requires a careful lab set-up for scales as small as your home shop DC.

10. **Grounding PVC works by removing charge at a point, and since charge must be uniformly distributed, it therefore removes charge everywhere.** There is no requirement that charge on an insulator be uniformly distributed.

11. **Getting a discharge outside the ducts, say to your finger, means you also have discharges inside the ducts.** As explained above, the electric field outside the pipe is generally much stronger than inside the pipe, so discharges outside are much easier to generate. In addition, you are a conductor and your finger is rather pointed. The the electric field at the end of your finger is especially strong for these reasons. This is why you generally gets discharges to your finger, rather than other parts of your body.

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