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Metal Hardening, Maximum Metal Strength, Liquifying, Vaporizing; Analogies for Each

Carl Littmann

25 Washington Lane #313, Wyncote PA 19095 USA

clittmann@verizon.net

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Abstract

This article presents ultra-simplified Analogies or models for the following: 1) What happens when some metals are cooled fast or by other physical methods - that makes them extra hard; but if done excessively – makes them brittle and prone to fracturing? 2) What happens as a solid goes through various states: I.e., adding heat raises a solid's temperature, then no increase with added heat– but melting occurs. Then, adding heat increasing temperature again; then no temperature increase with added heat while 'heat of vaporization' supplied. And then the vapor's temperature increases again? 3) Why does the strongest pure metal, Tungsten, obtain the high tensile strength it does, but not higher?

Keywords: Hardening, Venturi Suction, Laminar Flow, Turbulence, Fracturing, Annealing, Heat of Fusion, Tungsten, Tensile Strength, Phase change

Introduction

The Sketch immediately below is fundamental to understanding the relative 'Attractions' or Suctions that arise between layers of atoms, and is applicable to our 'Subject 1' (Hardening of Metals), below. And also likely relevant to the attractions between atoms in our 'Subject 2' (Solids-Liquids-Gases). And likely involved in our 'Subject 3' (Tungsten's great tensile strength). ((That is in contrast to merely a 'law' or 'rule' that 'opposite charges' just 'attract', (and like charges repel), which although a very useful rule -- I doubt if that rule, itself, is most 'fundamental'.))

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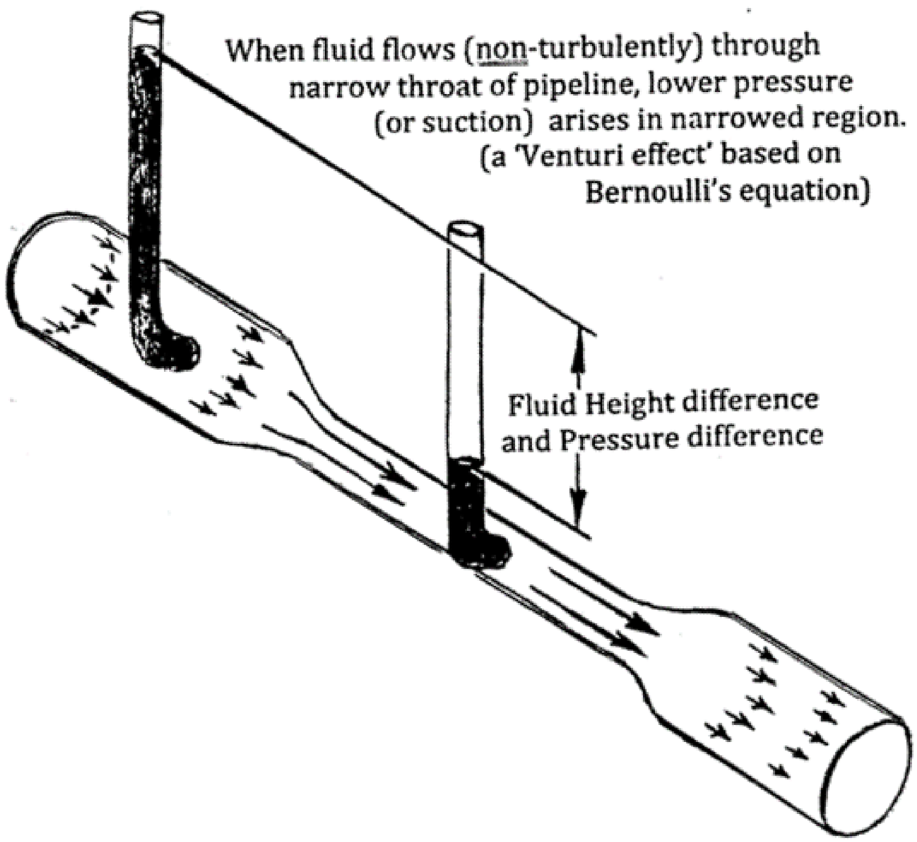


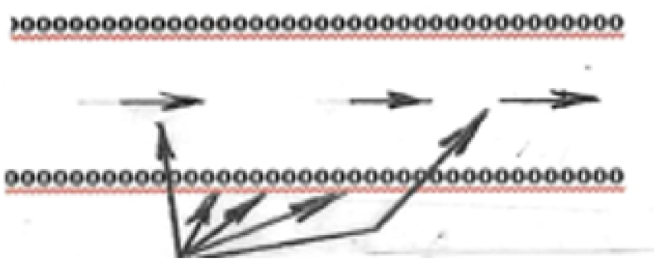
Optional Notes: Another basic article by Author, in The Gen. Sci. J., (GSj), is titled, "Geometric Ratios that nearly equal Mass Ratios of major Particles"; with link: /Research Papers-Quantum Theory / Particle Physics/Download/6726   Optional cont'd. . . I think the following analogy exists: A '**Compact**' particle must have a minimum amount of mass (about 200 electrons worth) to even have the possibility (by spinning at the speed of light) of manifesting, roughly, at least a "Planck's bar Constant" worth of "*Angular Momentum*". And thus, overcoming a 'Heisenberg Uncertainty' condition, and existing for an appreciable time. By comparison, many fluids must have a high enough value of (Reynolds Number x Viscosity), a product with 'dimensions' of "*Angular Momentum* / volume" to equal or exceed the fluid's ("mass/volume" x flow velocity x pipe diameter) so as to maintain a smooth 'laminar flow' and avoid the uncertainty or 'chaos' of 'turbulence' setting in.

. . . . SEE NEXT SKETCH BELOW, etc., as Main Article Continues . . . .

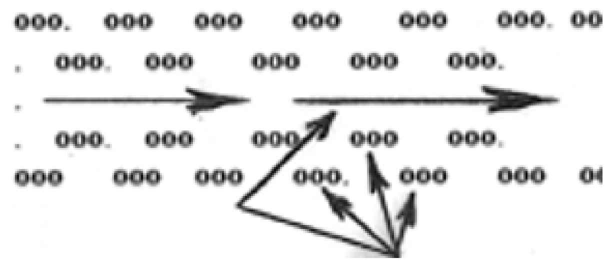
Subject 1, Hardening of Metals:

Roughly speaking, we concoct an analogy or model for the hardening of many metals that occurs by various methods, such as quick quenching (fast cooling) from a red-hot state. Or by introducing carbon atoms to their surfaces, or in some cases, by just much bending of the metal at room temperatures. And for the bad tendency for metals to become brittle and crack or rupture, if hardening is done excessively and without slow 'tempering'

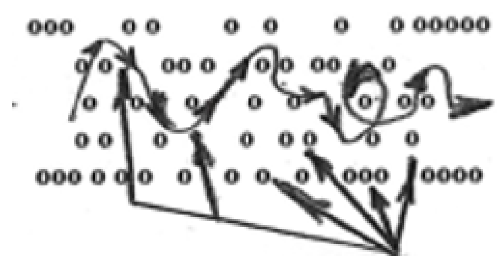
How the Venturi concept may relate to metal tensile strength:



(AT LEFT): Inline Nuclei: Result, a wider channel, slower flow, weaker '**Venturi**' effect, <u>less 'suction'</u>, and often less metal Tensile-strength than otherwise, but a more 'ductile' and easier-to-machine metal.



(AT MIDDLE): Somewhat 'Non-Aligned Nuclei'; thus, narrower channel cross-section, **faster** 'electric' fluid flow, causing greater '**Venturi'** effect, greater 'suction' or 'attraction', and thus, likely, **greater** metal **tensile strength**.



(AT LOWER RIGHT): Nuclei **<u>too disorderly</u>;** Turbulent flow occurs; **<u>Venturi effect</u> and suction <u>lost</u>;** and **<u>fracturing</u> of metal results.**

Incidentally, larger nuclei can also cause a narrower cross-section, and thus a similar increased metal tensile strength.

Many isotopes, with same numbers of proton but extra neutrons, have greater tensile strength and higher melting points, but are more brittle.

Our analogy involved imagining that there is some 'electric flow' between layers of atoms and their nuclei. Since an old, long-existing model of atoms involves electrons orbiting the nuclei somewhat like planets around the sun; some sort of electric flow may be expected, maybe it is even ‘cyclic’. Then we consider that that flow might result in Bernoulli and Venturi flow effects, when that electric flow is squeezed or constricted as it flows between layers of atomic nuclei. And thus, the relative ‘lower-pressure’ or seemingly ’increased attraction’ may arise between layers of atoms -- when such flow occurs. Higher flow speed occurs in those constricted regions. Thus, a ‘suction’ or ‘attraction’ would occur between layers, but that would still be dependent on there also existing considerable unobstructed space in some regions near the atoms and nuclei. And very importantly, a non-turbulent, **laminar** smooth ‘electric fluid flow’ must exist to maintain the relative low pressure, suction, or so-called ‘attractions.’

That model envisions that a properly hardened metal has some atoms slightly ‘**out** of line’. And so a slightly increased electric flow speed occurs between such layers, and thus a slightly greater ‘attraction’ or increased ‘hardness’, of the metal results. (That increased fluid flow speed is necessitated by a ‘theorem’ requiring that the same total fluid mass flow through a somewhat restricted cross-section per second – as would flow through a comparatively unobstructed cross-section per second, connected inline to the same flow system. And assuming that the fluid is virtually incompressible!)

Thus, by somewhat fast cooling of a hot metal, or by a random ‘doping’ of its surface with carbon or other process -- that leaves some nuclei ‘out-of-alinement’ and causes some obstruction to neat unimpeded ‘electric fluid flow’. And as inferred, to achieve the former same flow volume per second, the fluid moves faster through the now somewhat **constricted cross-section**. Thus, more narrowing, faster velocities, and greater Venturi suction (attraction) and a **harder metal** arises! (No longer is the metal somewhat like ‘dead-soft’ copper tubing, which is easy to bend and work with).

Lastly, too fast of cooling will catch too many atoms too far out of alignment, and too much impediment to flow will result. And thus the fluid speed will have to overly increase to get around the obstructions. Thus, although extreme hardness may be achieved, a greater tendency for the flow to turn **turbulent** will also result. And with that, **embrittlement**, a tendency for the **metal to crack** or rupture. So, our analogy to that is that “the ‘electric fluid’ **flow turns turbulent**, and is **no longer laminar** flow, and all **Venturi suctions ceases**, i.e., **attraction, is lost**!” That is like an airplane attempting a greater and faster lift by slanting its wings too far toward the vertical, i.e.., too great of ‘angle-of -attack’. And, thus, the airflow over the wing turns ‘turbulent’, efficient lift force is lost, and, thus, the airplane suddenly ‘**stalls-out’**. So, again, that is our analogy for excessive metal hardening being attempted, and thus embrittlement and rupture occurring!

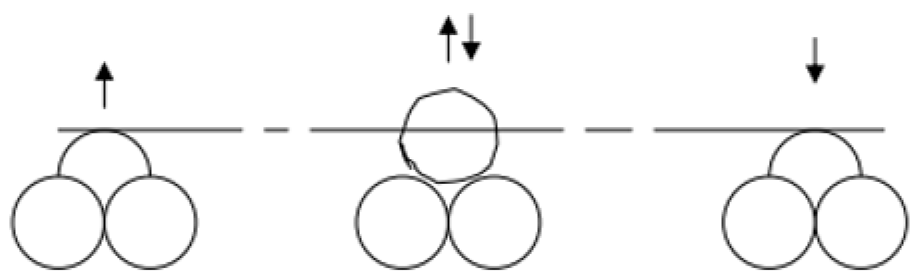
Regarding the phenomenon of fluid ‘laminar’ (orderly) flow turning ‘turbulent’ (with unwanted random eddy-currents) – Osborne Reynolds famously addressed that with his ‘Reynolds Number’, and formula. I believe Reynolds’ work was a ‘precursor’ to, and related to, the very important discoveries to come shortly thereafter, in the early 20th Century – Heisenberg’s Uncertainty Principle and Quantum Mechanics! ((**Optional**: That might be seen by noticing that ‘Reynolds Number’ = fluid ‘density’ x ‘velocity’ x pipe’s ‘diameter’ / ‘viscosity’. Then bring the ‘viscosity’ term over to the formula’s left side, and the ‘Reynolds Number’ to the right side. Then substitute for the ‘viscosity’ term – the molecular fluid’s (‘angularly momentum’ / unit volume), an expression with the same ‘dimensions’ as viscosity, (and indeed approximating it in many cases). And then noting that “Planck’s constant” also has dimensions of ‘<u>angular momentum</u>’. Lastly, substituting for the ‘density’ term, (‘mass / unit volume’), and noting that the ‘volume’ term on right and left sides of formula cancel out.))

Subject 2, Heating of metals, etc., and ‘change of phase’ occurring:

Roughly speaking, we also concoct an analogy or model for typical events that happen as most solid metals are heated. With heat continually added; first, we note the substance temperature increases; then liquifying -- but without an increase in temperature while its ‘heat of fusion’ is overcome during that liquid forming. After liquifying, an increase of liquid temperature resumes, since, here we imagine that “the adding of heat never ceased”. Then vapor begins to form, but without the temperature increasing while ‘heat of vaporization’ continues to be supplied. After completing all that, vapor temperature begins to increase again.

For our analogy, we start by imagining that 3 balls or atoms touch each other, and that they are positioned in a triangular array and in the same plane. The 2 in front are imagined as fixed in place, and the one behind the two -- bounces higher and higher with heat added and increasing temperature. The ball in back travels a limited short route. As temperature and heat absorbed increase – the ball moves up and toward the ‘lowest passage’, (like a mountain pass), between the 2 balls in front, (but, importantly, <u>**not**</u> **yet to the tip-top** of front balls, i.e., and thus <u>**not**</u> **yet** to the ‘**boiling’ stage –** that stage to be discussed later!)

Analogies for the States of Matter:

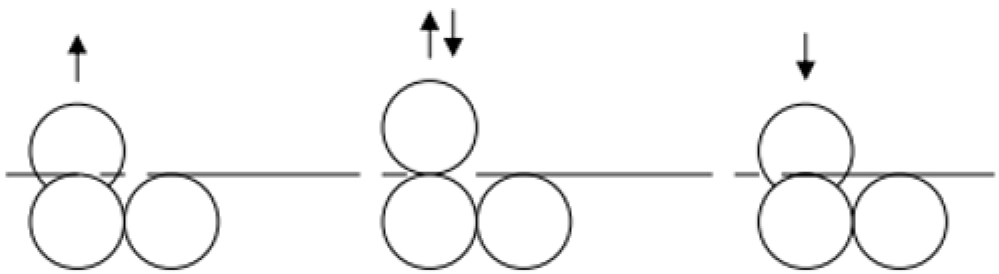


<u>Analogy for a Solid absorbs heat</u> and its temperature rises to melting point.
Upper sphere can vibrate up to the level of the “lowest passage way”, as shown.

When the back ball finally gets high enough to **pass-over the lowest ‘pass’ between the 2 front balls**, we then imagine that **melting of the solid begins**! Then no temperature increase occurs until almost all other balls absorb enough heat to get to that ‘pass-overing’ height. (I.e., the point of over-coming the ‘heat of fusion’.) But after that, the temperature of the liquid increases again -- with added heat, i.e., heat is energy! When most of the balls get high enough to achieve that, we imagine, here, that their movement has achieved a new ‘degree of freedom’, i.e., the sliding down and up the other side of the so-called ‘mountain-pass’ -- is now possible They are no longer restricted by their having to scrape neighbors as they merely <u>almost</u> got ‘over the lowest passage point’; but can now go over and down the slope on the other side, and in other directions. Thus, here we imagine that ”more ‘degrees of freedom’ of movement have now become available” to the ‘jumping atoms.

So, perhaps that helps us imagine that, now, continuing to add the same amounts of heat as previously, (i.e., after full transition to the liquid phase has occurred), now causes a lesser temperature change than occurred in the prior (solid) ‘phase’! I.e., Thus, our model or analogy seems to infers that there are now additional routes of movement for the atoms, rather than just ‘up’. I.e., now, other ways to ‘express’ their added increased kinetic energy of movement. Anyway, in many cases. it takes about twice as much added heat, to a substance in its liquid state – to achieve the same temperature increase as was obtained in its solid state!

Finally, our visualized ‘ball-in-back’ jumps high enough, even, to get to the tip-top of the balls in front of it. (That is analogous to reaching the ‘boiling point’, which we, thus, now imagine has been reached’!)



<u>Analogy for Liquid absorbs heat</u> and its temperature rises to near boiling point.
Upper sphere can vibrates up to the tip of the highest sphere below it.

Then there is no temperature increase until almost all balls or atoms have been provided enough heat or energy to jump that high. But importantly, and as previously inferred, for all the atoms to get that high ‘peak’; a comparatively huge amount of heat had to be added, i.e., to supply the ‘heat of vaporization’. After nearly all atoms have reached the height of the tip-top of the front balls, vapor temperature begins increasing with added heat. (This analogy or model may fall short of explaining or inferring as to why, in the ‘vapor state’, the specific heat value decreases vs. its value in the previous, liquid, state. Perhaps it relates to the space between atoms in the vapor -- being so far from the neighboring atoms -- that the former so-called ‘forces of attraction’ no longer have a great effect.)

Subject 3, Analogies, ‘how metals, like Tungsten, achieve high tensile strength, but not higher’:

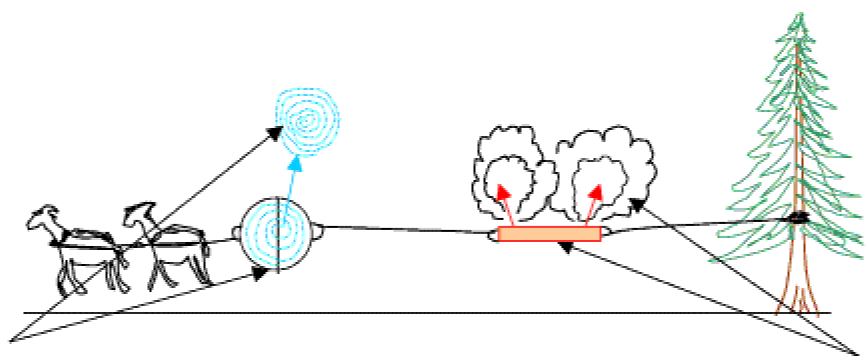
We now show that there is likely an interesting relationship between two physical events that might otherwise appear unrelated. And examples of the two events, to be contrasted, are as follows:

<u>First example</u>; when air, (or the kinetic <u>Energy</u> of air), is removed from the interior of two touching hemispheres, the two hemispheres cling together with great external pressure, i.e., here we say, ‘<u>negative</u> pressure, because ‘energy was emitted’ (or ‘energy escaped’ when air

was sucked out by the pump). And so much so, that in 1654, Guericke demonstrated that even many horses could not pull apart his two evacuated 'Magdelburg hemispheres', i.e., the relatively higher exterior air pressure was then effective at pushing the hemispheres together very hard. (But if observers did not know about that exterior air pressure, they might think the two hemispheres had fused together and were strongly held together by their metals' tensile strength!)

Note Sketch below, (applicable to First Example above and Second Example below:

Two cases of "energy per volume removed from vessels" are shown below. For a comparison of the "suction" strength (per area) and the "tensile" strength (per area) that can arise, see Article, (after noting descriptions below).



(UPPER **LEFT**): Guericke showed that if he pumped a certain amount of air (i.e. air having energy per volume) out of two metal hemispheres in contact, great "**suction strength**" would occur, and even several horses could not pull them apart.

(Upper **RIGHT**): A **hot bar** of metal is shown solidifying, "heat of fusion" is given off; (i.e. a certain amount of energy per volume is given off), and a certain amount of "tensile strength" can thus develop.

Second example; when heat (i.e., Energy) is removed from, say, a cubic inch 'bar' of 'solidifying' tungsten, its 'heat of fusion' is emitted; and that leads to the solid tungsten developing a high 'tensile strength', i.e., a sort of negative Pressure, because energy was emitted.

Note, in both the first and second examples, above, Energy per Volume was emitted, and a sort of negative Pressure, or 'tensile strength' arose. In fact, Energy per Volume has the same equivalent 'units' or 'dimensions' as Pressure, and thus, Energy per Volume can be expressed as Pressure! And we show that as follows:

Energy / {Volume} = (Force x Length) / {Area x Length} = [(Force) / {Area}] x [(Length)/{Length}] = [Pressure] = [(Force) / {Area}]. . . . . I.e., So the emitted 'Energy per {Volume}' is equivalent to 'Tensile Strength',— regarding '*units used*' or '*dimensionally speaking*'. And we'll exemplify that, using tungsten, later in this article.

And, importantly, this motivates us to ask, "how efficient are the two different examples above, the First (Guericke's hemispheres), vs. the Second (solidification of metals when 'heat-of-fusion' emitted) – at forming an entity that is hard to 'pull apart'? I.e., How efficient at creating 'suction pressure' or 'tensile strength' when a given amount of 'Energy per unit volume' is removed from each?"

For example, we may ask: "Suppose (using basic laws of 'Ideal Gas Theory') -- that Guericke's hemispheres became 'suctioned together' by a 'negative' pressure equal to **67%** of the 'kinetic energy' of the air molecules pumped out of those touching spheres. How does that compare with a metal's useful 'Tensile Strength' that metals can develop after the metal, say a cubic inch of it, gives off an equivalent amount of 'energy per volume' during its 'heat-of-fusion' process? I.e., does the metal develop a tensile strength equal to about 67% or 85% or 100%, or some other percent -- of the 'energy per volume' that is removed from it? The actual outcome for 'hard-drawn' Tungsten, the metallic element with the highest maximum tensile strength – is about **85%**, vs. about 67% for the case of Guericke's hemispheres when the kinetic energy of air molecules was pumped out of it. I.e., for the Tungsten's case, very roughly about 85% of its 'heat per volume' removed, during its 'heat of fusion' process, becomes 'useful or salvageable' as Tungsten's 'Tensile Strength' developed.

In the above examples, we simplified our calculations -- by imagining that our so-called 'hemispheres' were actually 'cube-shaped' 'shells', with a strong, thin wall surface that was cut in half", instead of two spherical 'hemispheres'. And we imagined that our cubic inch of tungsten's developed great tensile strength after 'heat per volume' was removed during its solidification or 'fusion'. And we compared the amount of 'heat per volume' removed -- to the eventual 'tensile strength' that can be developed in Tungsten – but which is just a 'tensile strength stored-up', immediately after solidifying. I.e., and that great tensile strength only manifested after the very hot tungsten cube was allowed to cool-down a lot. In our analogy or model, here, we imagine that, initially, when the metal's temperature is still near its melting point, its strength is still weak, stored up, and not yet manifested until cooled a lot. (That additional cooling removes 1 to 2 times as much heat for most metals.)

Adding some other 'technical comments'; we note that we will obtain Tungsten's 'emitted energy per volume' during its fusing, as follows:

Its Energy / {Volume} = its 'heat of fusion', expressed as (Energy / *Mass*), multiplied **times** its 'density', expressed as (*Mass* / Volume), = Energy / Volume; because 'Mass/Mass' 'cancels out', i.e., equals 1 or 'unity'. . . . . . So, we obtain from old tables, Tungsten's (**W**) and Molybdenum's (**Mo**) listed 'heats of fusion' [ref. **1**] and their 'densities', for our further calculations and use. We also noted (that after 'hard-drawing') --- the tensile strengths of (W)'s, and the metal with next highest tensile strength, Molybdenum, (**Mo**), [ref. **2**] And we compared those tensile strengths to their 'heat per volume' emitted, during the fusion process. I.e., Ratio results, roughly 85% for (W), and **65%** for (**Mo**). Note, the (Mo) outcome is about the same as for our imagined cubic 'hemispheres', when the energy of air was pumped out of them. But the **85%** 'efficiency' associated with Tungsten (**W**) is higher than (Mo); but still less than **100%**. (In the periodic table, both 'W' and 'Mo' belong to 'group VI'.) The other elemental metals have, comparatively, medium to low tensile strengths. And that seems to arise because, as we note, they generally exhibit lesser 'heats of fusion' and generally lower densities. And even, along with all that, they have a lower 'efficiency' of transforming their lower 'heat of fusions' into 'tensile strength' -- as well.

We also note that Tungsten has a very high density, much higher than lead. And Tungsten's nuclei also have more protons and neutrons than that of most other atoms. And thus tungsten's nuclei provide a greater size or 'cross-sections' than is the case for most other elements. Both those attributes, using our analogies or modeling, should help assure, respectively, a relatively thick (high density) imagined 'electric flow volume' and a greater 'constriction of such flow'. Both those characteristics should cause a greater 'Venturi Suction' or 'Tensile Strength' to be developable, using our analogies and modeling, regarding imagined 'electric fluid flow', and our applying Bernoulli's equation and the 'Venturi effect' to that. And so the relatively very high 'ultimate tensile strength' that Tungsten has – should not come as a surprise, using our above analogies or modeling. (Again, note all data above are very rough approximations. Yet, for strong metals, fusion heats per volume are 'within the ballpark' of tensile strengths developable, and in some ways remind one of Guericke's old experiment.)

Miscellaneous Closing Comments

In the discussion, above, involving topics 1, 2, and 3; we have attempted to view the over-all actions 'from a distance', like 'discerning the 'forest from the trees'; and that is a 'holistic' approach. Often that entails viewing many seeming different actions in Nature; but noting that some of them, yet, have an important aspect 'in common', i.e., in some way are alike. And thus, mentally classifying them, in a sense, into a special group for special study and comparison. In effect, I think such approach has sometimes resulted in important advances, like the case of Mendeleyev's 'Periodic Table', and Linnaeus's 'biological classification system' (the latter based on incremental, but basic, 'system' advances associated with the organism's increased complexities and specialization). That can often be done even **without having a theory** as to how or why the special similarity among different things - arose! But the discovering or identifying the common, basic, useful and unifying 'thread' often requires that the discoverer be astute. He/she must not only "view what many others have also viewed; but think about it in a way that nobody else has yet to have thought!"

I think my treatment of topic 1 above -- comes closer to being a good, useable 'model' or 'analogy', than, say, my treatment of topic 2, and maybe topic 3. In fact, my treatment of topic 2 may not reach as high as a simple good analogy; and may be rather closer to just 'allegorical'.

Optional: One might wonder, regarding good 'attribution practices', if my above treatments, are original, or how much so? And I don't really know! That motivates me to propose that some Online Journals, each with 50,000 articles/papers or more, include an optional, efficient alphabetical 'Search by-Subject' feature to ferry the inquirers through an internal search of their journal. And thus to find papers/articles about topics relevant to the searcher. I.e., and, thus, not totally relying on 'Google Search' or a near-alike. And that should be very easy to provide, since many of those journals already have an automated alphabetical 'Search-by-Author' feature, and located even on the Journal's 'home page'. But now consider a different use for the 'Search-by-Author' program since it already invites, in effect, 'keying in' **<u>3 words</u>** (**instead of <u>3 names</u>**). That same type program awaits just using it for a 'search-by-subject'! In fact, some Online Journals even handle 4 name 'blanks', not just the usual 3 names 'blanks' or 'fields'. ((Of course, 'mouse-clicking' an icon, adjacent the 3 'subject-related words', would instantly 'ferry', (or link), the reader on-over to the article or paper, relating to the subject of likely interest the prospective reader or researcher.))

So, using the same 'programming method' (or 'field') as used in the 'Search-by-Author' method; I suggest, making good use of '**crowd-sourcing**', in a sense, as follows:

Invite each author, themselves, optionally, to 'holistically', thoughtfully, and carefully concoct **3 words** that would help a prospective 'searcher, by subject', link to the author's article – i.e., under what topic or subject should his/her choose for listing his/her paper? For example, for a 'Physics Journal', "<u>Particle</u> <u>Mass</u> <u>Ratios</u>". (Many online journals even allow very long names of authors to be listed, i.e., even with 15 characters, (or letters), for the spelling of their first, and for their middle, and for their last name. So a 'Search-by-Subject' option could even cleverly allow 'words-jammed-together', to provide more details in one long-lettered word. For example, "Particle MassRatios WhyExactlyEach". And there are many other variations as to how a very effective 'Search-by-Subject' feature could be designed. But very importantly, Online Journals could and should provide suggestions to the searcher, not just for the article's author, as to how to efficiently use the particular 'Search-by-Subject' feature. That includes encouraging the searchers -- to change their order of words, they 'keyed in' (typed in) – if their first-attempted word-order didn't yield productive results. ((If nothing else, the proposed 'internal' alphabetical 'Search-by-Subject' feature, would enable the searcher and a prospective article writer, to show that -- "they <u>first</u> made an earnest search, before writing their paper".))

References:

Ref. **1**. <u>Handbook of Chemistry and Physics</u>, 73rd ed.; CRC Press: Boca Raton, Fl. 1992, "Thermal and Physical Properties of Pure Metals", 12-130-131

Ref. **2**. <u>Handbook of Chemistry and Physics</u>, 43rd ed.; Chemical Rubber Publishing Co.: Cleveland, Oh. 1962, "Elastic Constants for Solids", pp 2164-2168, and "Tensile Strength of Metals", p 2188. (Note, that values considered only **approximates**).