The Effect of Wood Hardness on the Speed of Fire By Friction

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Part One: Inspiration and Background

Pragmatically, the inspiration for this project is drawn from a series of backpacking excursion I embarked upon with my brother and father two years ago, which in the end totaled approximately 120 miles. Now the golden maxim of backpacking is to pack frugally. So, every day as I repacked my backpack, I would glare angrily at the extra weight of fire by friction set material I had to carry with me because it made the overall weight of my bag very onerous. Then, as I trudged along the trails throughout the day, I started to mull over the idea of possibly constructing the optimal fire by friction set. The more and more I thought about it the more and more that I wanted to find the answer to this curious concept. Subsequently, when my junior year started, I decided that I had to investigate this query of mine, so immediately started doing some background research. After I had constructed my experimental procedure and design, with an insatiable appetite for answers, I traveled to my laboratory, my garage, and embarked on my own odyssey through the world of science as I initiated the first phases of my research plan.

As a true foray into scientific technique, my research project has instilled in me the importance of carefully developing an experimental design and procedure. Since my project champions the scientific process in order to answer a question which most people would not ask, it challenges humanity to attempt to answer atypical questions. Many high school students ask spectacular questions about modern day dilemmas, but have no procedure to follow in order to begin the process of finding an answer. If no process has been defined to overcome these obstacles when they arise, then how will anymore scientific discoveries take place? Due to this critical conundrum, I encourage high school students interested in asking questions to cultivate analytical problem solving skills. Also, I urge them to embrace science and the scientific process as they strive to solve problems in their own lives so that ultimately, once they find a curious phenomenon, then they will have the confidence to start unraveling this mystery by utilizing the scientific process.

Moreover, Thomas Edison once espoused that many people miss great opportunities because they come dressed in overalls and look much like work. Similarly, like cutting an onion, scientific research can be an onerous task; therefore, I challenge high school researches to embrace tenaciously all opportunities by continuing to work on a project until it has been completed successfully and never being afraid to go the extra mile in order to accomplish a task. When I encountered obstacles, I discovered how to search for other resources to help me learn how to find the answer myself, such as learning statistics in order to be able to analyze my results. After consulting both textbooks and statistics teachers for advice, I had compiled enough resources to practice and to learn about both Chi Square and ANOVA statistical tests. Not only did I cultivate skills in statistics, but I also gained a greater appreciation for the importance of mathematics to analyzing results and communicating conclusions since mathematics is the universal language of science. Furthermore, my research project encouraged me to delve deeper into other areas besides statistics.

Finally, conducting research has also taught me that science is not something that happens just in isolation. While I have observed that collaboration is an adult phrase used to soften the idea of asking for help, I also believe that it stands for the prospect of learning from others as we work to answer fundamental questions in our lives. Thus, I believe that collaboration is crucially important to the advancement of science research. Yet, even more so than this, I believe that science should be a collaborative global initiative to answer questions that add to the foundation of our expanding knowledge. Therefore, I advise high school students, who are interested in research, but also timid about starting their own projects, to collaborate with other students and with teachers in order to gain both valuable insight and a different perspective toward a perplexing problem.

Most of all, I have discovered that scientific inquiry for the sake of science is the most educational and worthy exploration of all. So, in closing, the value of any scientist's research is not determined by whether they performed experiments in a garage or in a professional lab, but instead the value of the research is determined by how much of the researcher's initial curiosity for a question that had meaning to the researcher transformed into: the patience to construct the methods of the project, the persistence to carry out the methods meticulously and to analyze the results carefully, and finally the passion to take time at the end to share the conclusions of the research with fellow scientists in order to increase the ever-expanding knowledge of humanity.

Part Two: Research Section

The Effect of Wood Hardness

on the Speed of Fire By Friction

Without a doubt, one of the greatest innovative breakthroughs of the ancient world would be systematic creation of fire. One of the most efficient methods ancient people used to create fire was the process of fire by friction. This process involves harnessing friction by forcing a spindle to rotate and to bore into a floorboard which in turn produces an ember (Appendix A). Today, engineers, who are captivated by the characteristics of friction, devote their research to the field of Tribology. Tribology is the study of the characteristics of friction, lubricants, and the wear of materials due to friction.

As an avid backpacker and camper, the ability to fabricate a fire quickly and efficiently is a necessity. The results from this experiment are important because it has the potential to aid the backpacker, who carries only the necessities, and thus reducing the load carried. At the conclusion of this experiment, the analysis of the experimental data will highlight which combination of woods with varying hardnesses will yield the fastest ember formation for fire by friction. This combination will be the backpacker’s ideal fire starter.

Furthermore, the purpose of this experiment was to investigate if the combination of a spindle made of harder wood and a floorboard made from softer wood would have a negative effect on the time necessary for an ember to form, which is referred to as speed. Ember formation is crucial in the process of fire by friction. Before performing the experiment, wood samples were collected and sorted based on their relative hardness. Relative hardness refers to the arrangement of the plant cells. Harder woods have plant cells which are more closely compacted in the same cubic millimeter than the cells of a softer wood. This close compaction of cells in a harder wood, the higher amount of lignin, which is a benzene ring polymer, in the plant cell walls of harder woods, and a higher specific gravity of harder woods are what account for the distinct contrasts between hard and soft woods. A total of 108 spindles and six floorboards were then fabricated for experimental purposes. By using a drill press to apply downward force, rotational speed, and alternating rotational direction, the human fire by friction process can be simulated in a scientifically controlled situation. This controlled situation will test for the effect of wood hardness on the speed of fire by friction. Repeating each combination with varying hardnesses of spindle and floorboard a total of three times provides enough quantitative data necessary for a Chi square analysis (Sharp). First, implementing the ANOVA test highlighted that the experimental data contained minimal error. Next, the statistical Chi squared data will reveal that the hardest spindle in conjunction with the softest floorboard yields 35.6% faster ember formation than the combination of the softest spindle on the hardest floorboard.

Both analytical thinking and research were used in the process of developing the hypothesis for this experiment. First, by approaching this problem analytically, it can be concluded that the abrasive characteristic of harder woods would cause a spindle made of this wood to bore much faster and more efficiently into a floorboard composed of softer wood. Furthermore, the friction would be optimal for this combination since a larger area of the harder spindle would experience the force of friction as the hard spindle bores further into the softer floorboard. In addition, T. A. Joyce, a well-known and respected anthropologist, concluded in one of his article based on his research that the majority of ancient cultures in Central Asia used woods with dissimilar degrees of hardness for the spindle and floorboard components of their fire by friction sets (Joyce 1911). Subsequently, the hypothesis, if a combination of harder wood for the spindles and of softer wood for the floorboard is implemented then the time necessary for ember formation will decrease, was formulated from the strong preliminary foundation. During this experiment the null hypothesis, if no specific combinations of soft or of hard wood for the different components of the fire by friction set are used then a faster ember will be produced, was the actual statement under investigation. Next, the data in this experiment was analyzed statistically using Chi square and ANOVA analysis. After completing the experiment and statistically analyzing the experimental data, it is important to report that the null hypothesis was refuted. Thus, the combination of the hardest wood for the spindle and of the softest wood for the floorboard is the optimal choice for the fastest ember formation.

Methodology

Experimental Design

Indeed, the plan for this experiment is to use a drill press to test combinations of fire by friction components made from both soft and hard woods in a controlled way in order to collect quantitative experimental data of the speed, as defined earlier, of ember formation. Once the substantial amounts of qualitative data have been amassed and analyzed, the ideal combination of wood types will be highlighted from the statistical analysis according to the time taken for ember formation. First, 108 uniform spindles and six floorboards will be made from six different types of wood commonly found in the surrounding Indiana community. The six species of wood collected for this experiment were: *Diospyras virginiana*, *Carpinus caroliniana, Pinus palustris, Juniperus virginiana, Liriodendron tulipifera,* and *Pinus strobus.* The regional common names for these species, in the same order, are: Persimmon, Ironwood, Southern Yellow Pine, Eastern Red Cedar, Tulip Poplar, and Eastern White Pine. To ensure that all of the woods will be tested under the same conditions, the wood will all be subject to a drying process. Using an oven, the wood samples are dried in order to deplete the largest amount of moisture present within the fibers (Reeb 1997). Next, a fire-by-friction machine with a drill press will be constructed and used (Appendix A). This is crucial because the experimental set-up ensures that the variables, rotational speed of the spindle, the amount of downward force, and the direction that the spindle rotates, are held constant. Also, it will be pertinent to record both the time it takes for smoke to appear and for an ember to be formed. An acceptable ember, for the purpose of this experiment, is an ember, which could burn a small amount of tinder with the aid of only one small, yet steady stream of air. It will be necessary for the experimenter to use both subjective and objective methods of data collection during the course of the experiment. For example, in order to document accurately the time taken for smoke to appear, the experimenter must use their visual and auditory senses to watch for the first wisp of smoke while listening for a frequency change in the noise created by the spindle boring into the floorboard. This frequency change occurs when the smoke starts to appear. In addition, during the experiment, it would be important to collect infrared thermometer measurements each time the rotation direction is switched in order to observe the progress of the ember formation process.

Experimental Procedure

Before starting, the wood samples should be sorted by degrees of increasing relative hardness, according to the Janka hardness test (*Janka* 2006). The Janka hardness test is a scientific test of wood hardness where the hardness is equal to the force necessary to push a steel ball with a set diameter into the wood to the radius of the steel ball (Appendix B). Next, cut each species of wood sample into spindles and floorboards. The floorboards should be rectangular prisms with a length of 30.4 cm, a width of 5.08 cm, and a height of 3.8 cm. In addition, a divot is made 0.635cm from the edge. The centers of the 1.27 cm diameter divots are separated by a distance of 1.9 cm. Cut a small v-shaped notch from the edge to the center of the divot. The spindles should be approximately 15.2 cm tall and 1.27 cm in diameter. The spindle should also be rounded into a cone at one end while leaving the other end flat. Dry the wood samples in an oven for five hours at 93.3˚C. Once dry, select a combination of floorboard and spindle, and place the flat end of the spindle in the drill press chuck while placing the tapered end of the spindle into the floorboard divot. A force of 44.5 Newtons is applied downward on the spindle. Record an initial infrared temperature reading and switch on the drill press to spin clockwise for 30 seconds. Switch off the drill-press, allow the spindle to stop, and reset the directional controller so that the drill press spins counter clockwise. The drill press is turned back on, and is allowed to rotate counter clockwise for 30 seconds. The new infrared temperature reading is recorded in the data table. Also, the time when smoke first appears is recorded in the data table. Continue this process until an ember has been produced. Record the time the combination takes to produce an ember. Repeat this process twice more for each combination, and then repeat the entire process of three trial runs for each possible combination of wood species.

Results

Table 1. Time for Ember Formation of Spindle V.S. Floorboard Combinations

(All time measurements for ember formation are averages in seconds.)

Decreasing Floorboard hardness →		Decreasing Spindle Hardness →					
		Diospyras virginiana (Persimmon)	*Carpinus caroliniana* (Ironwood)	*Pinus palustris* (Southern Yellow Pine)	*Juniperus virginiana* (Red Cedar)	*Liriodendron tulipifera* (Tulip Poplar)	*Pinus strobus* (White Pine)
	Diospyras virginiana	416	389	n/a	451	431	359
	Carpinus caroliniana	264	386	n/a	n/a	n/a	450
	Pinus palustris	316	380	375	389	n/a	283
	Juniperus virginiana	186	261	253	187	n/a	207
	Liriodendron tulipifera	141	211	322	262	n/a	281
	Pinus strobus	126	165	200	249	n/a	125

Note: the above table reflects a representative sample of the data for brevity. After completing a total of three trial runs of the 36 combinations of spindles and of floorboards, the data collected included a total of 108 pieces of experimental data. Please see Appendix C for the complete experimental data table.

Discussion

After completing the experiment, the data was compiled and analyzed using both Chi square calculations, which examine relationships for frequency, and ANOVA calculations, which searches for the presence of error (Appendix D). The statistical analysis reveals the fastest ember formation combination since both a frequency had been highlighted and relatively no error was found in the experimental data set. This combination is statistically shown to be a *Diospyras virginiana* (Persimmon) spindle, the hardest wood tested, paired with a *Pinus strobus* (Eastern White Pine) floorboard, the softest wood tested.

It was shown that the null hypothesis, no combination of hard and soft woods would cause faster ember formation, was refuted by statistical analysis. Because the null hypothesis has been rejected, the initial hypothesis, if the combination of a spindle made of harder wood and a floorboard made from softer wood would decrease the time necessary to form an ember, is supported by the experimental data and statistical analysis. It would be presumptuous to say that at this point that the hypothesis is without error or flaw because not all species of wood have been tested. In addition to the application of the experiment's conclusion for the camper and backpacker, the results from the experiment can also be applied to how friction affects other materials such as metal or plastic. This is important to understand because the knowledge of the effect of friction on components of moveable parts could prevent the premature failure of components with different relative hardnesses which are paired together inside a machine.

Moreover, the procedure was very effective in gathering enough quantitative experimental data with which to utilize both Chi square and ANOVA calculations for statistical analysis (Appendix D). Furthermore, an effective engineering model that simulated a traditional fire by friction set was produced which optimized the process by making additional variables such as downward force or rotational speed standard. Moreover, additional exploration was made into the physical particle sizes and characteristics of the dust by-product to learn more about how else the different combinations of varying wood hardness for the components effected the process of ember formation. Next, qualitative analysis of these observations reveals that the smaller dust by-product particles are generated when either that both the spindle and floorboard have a converging equal relative hardness or that the spindle has a higher relative hardness than the floorboard. In contrast, the larger pieces of dust by-product are generated when a softer spindle is paired with a harder floorboard. For future study, chemical or further physical analysis of dust samples or by-products of the fire by friction process could reveal more about the relationship of hardness to ember formation speed. Also, different species of Indiana trees or more diverse species not common in Indiana could be tested. Furthermore, investigation of a relationship between the areas of the burnt spindle cones to the speed of ember production could be made. Moreover, a relationship between the flashpoint point of the woods and the combinations of woods could be investigated.

Table 2. Standard Deviation of Time for Ember Formation of Spindle V.S. Floorboard Combinations

		Decreasing Spindle Hardness →					
		Diospyras virginiana (Persimmon)	*Carpinus caroliniana* (Ironwood)	*Pinus palustris* (Southern Yellow Pine)	*Juniperus virginiana* (Red Cedar)	*Liriodendron tulipifera* (Tulip Poplar)	*Pinus strobus* (White Pine)
Decreasing Floorboard Hardness ↓	*Diospyras virginiana* STDEV	0.0227	0.0118	0	0.0354	0.178	0.1
	Carpinus caroliniana STDEV	0.0241	0.0503	0	0	0	0.18
	Pinus palustris STDEV	0.0759	0.0183	0.00382	0.0311	0	0.0333
	Juniperus virginiana STDEV	0.0228	0.0102	0.00372	0.195	0	0.0353
	Liriodendron tulipifera STDEV	0.022	0.0251	0.00606	0.0105	0	0.0188
	Pinus strobus STDEV	0.0357	0.00834	0.033	0.035	0	0.0275

Table 3. Chi square Calculations of Time for Ember Formation of Spindle V.S. Floorboard Combinations

		Decreasing Spindle Hardness →					
		Diospyras virginiana (Persimmon)	*Carpinus caroliniana* (Ironwood)	*Pinus palustris* (Southern Yellow Pine)	*Juniperus virginiana* (Red Cedar)	*Liriodendron tulipifera* (Tulip Poplar)	*Pinus strobus* (White Pine)
Decreasing Floorboard Hardness ↓	*Diospyras virginiana* Chi Square	0.919	0.932	0.688	0.916	0.875	1
	Carpinus caroliniana Chi Square	0.949	0.982	0.687	0.687	0.687	0.818
	Pinus palustris Chi Square	0.945	0.964	0.952	0.969	0.687	0.94
	Juniperus virginiana Chi Square	0.897	0.947	0.932	0.902	0.688	0.93
	Liriodendron tulipifera Chi Square	0.869	0.922	0.964	0.943	0.687	0.966
	Pinus strobus Chi Square	0.841	0.891	0.908	0.96	0.687	0.851

References

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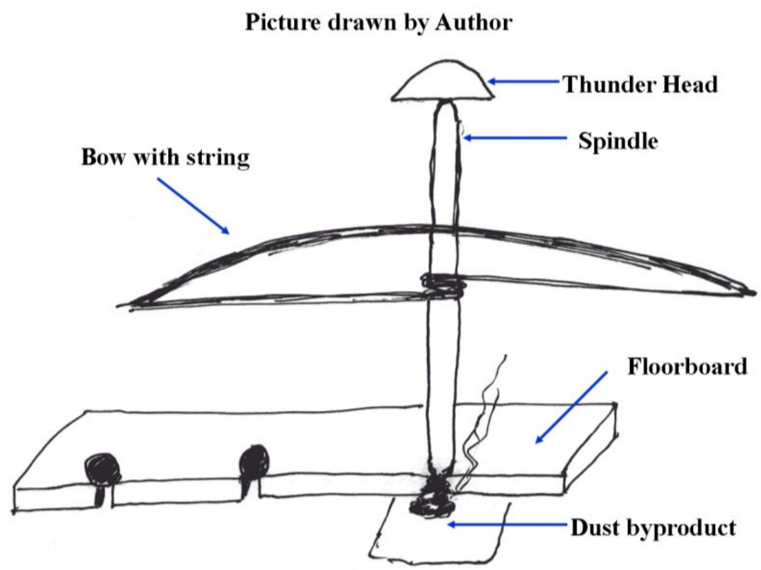
Appendix A

Diagrams and Pictures

Diagram 1. A Traditional Fire By Friction Set



Picture 1. Drill Press Experimental Set-Up

Appendix B

Table 4. Relative Hardness According to the Janka Hardness Test For Wood Species

Species of Wood	Relative Hardness
Diospyras virginiana (Persimmon)	10.23 kN
Carpinus caroliniana (Ironwood)	7.92 kN
Pinus palustris (Southern Yellow Pine)	4.05 kN
Juniperus virginiana (Eastern Red Cedar)	4.00 kN
Liriodendron tulipifera (Tulip Poplar)	2.40 kN
Pinus strobus (EasternWhite Pine)	1.87 kN

Appendix C

Complete Experimental Data.

Table 5. Complete Experimental Data All Trial Runs

(All time measurements for ember formation are in seconds.)

Decreasing Spindle Hardness →

Increasing Floorboard Hardness ↑

	Diospyras virginiana (Persimmon)	*Carpinus caroliniana* (Ironwood)	*Pinus palustris* (Southern Yellow Pine)	*Juniperus virginiana* (Red Cedar)	*Liriodendron tulipifera* (Tulip Poplar)	*Pinus strobus* (White Pine)
Diospyras virginiana Trial 1	381	375	n/a	502	n/a	510
Diospyras virginiana Trial 2	446	385	n/a	400	370	349
Diospyras virginiana Trial 3	421	408	n/a	452	492	220
Carpinus caroliniana Trial 1	242	460	n/a	n/a	n/a	450
Carpinus caroliniana Trial 2	304	391	n/a	n/a	n/a	n/a
Carpinus caroliniana Trial 3	246	315	n/a	n/a	n/a	n/a
Pinus palustris Trial 1	407	410	375	420	n/a	297
Pinus palustris Trial 2	195	390	381	410	n/a	230
Pinus palustris Trial 3	248	350	370	338	n/a	323
Juniperus virginiana Trial 1	149	268	198	160	n/a	266
Juniperus virginiana Trial 2	210	244	305	216	n/a	181
Juniperus virginiana Trial 3	201	271	258	185	n/a	175
Liriodendron tulipifera Trial 1	169	241	332	260	n/a	310
Liriodendron tulipifera Trial 2	150	171	320	249	n/a	278
Liriodendron tulipifera Trial 3	105	222	315	279	n/a	256
Pinus strobus Trial 1	75	178	155	298	n/a	140
Pinus strobus Trial 2	178	165	250	255	n/a	155
Pinus strobus Trial 3	125	154	197	195	n/a	80

Appendix D

Statistical Analysis Formulas and Description

1. The equation depicted below was used for Chi square calculations.

Equation 1: $$x^2 = \frac{(O-E)^2}{E}$$

2. The following table is a brief description of the ANOVA calculations.

Table 6. The Description of the ANOVA Statistical Analysis

"Between"	BSS	dfB	BSS/dfB = BMS
	2,264,304	35	64694.4
"Within"	WSS	dfW	WSS/dfW = WSS
	2922.16	105	27.83
F-Test = BMS/W MS = 6469.44/27.83 = 232.46			