Figure-Eight Steel Wool Sparks: Long-Exposure Photography

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Date: October 7, 2026
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1. Introduction and Intent

I wanted to use long exposures for this project and take pictures of steel wool on fire. I tried to get the steel wool to make a figure eight shape with the sparks while still being able to see what's around it. I decided to take pictures of this because you can't really see what it is doing while it's going. So by taking pictures with long exposures you can see what path it is traveling in. I also wanted to show what was around the steel wool as well.

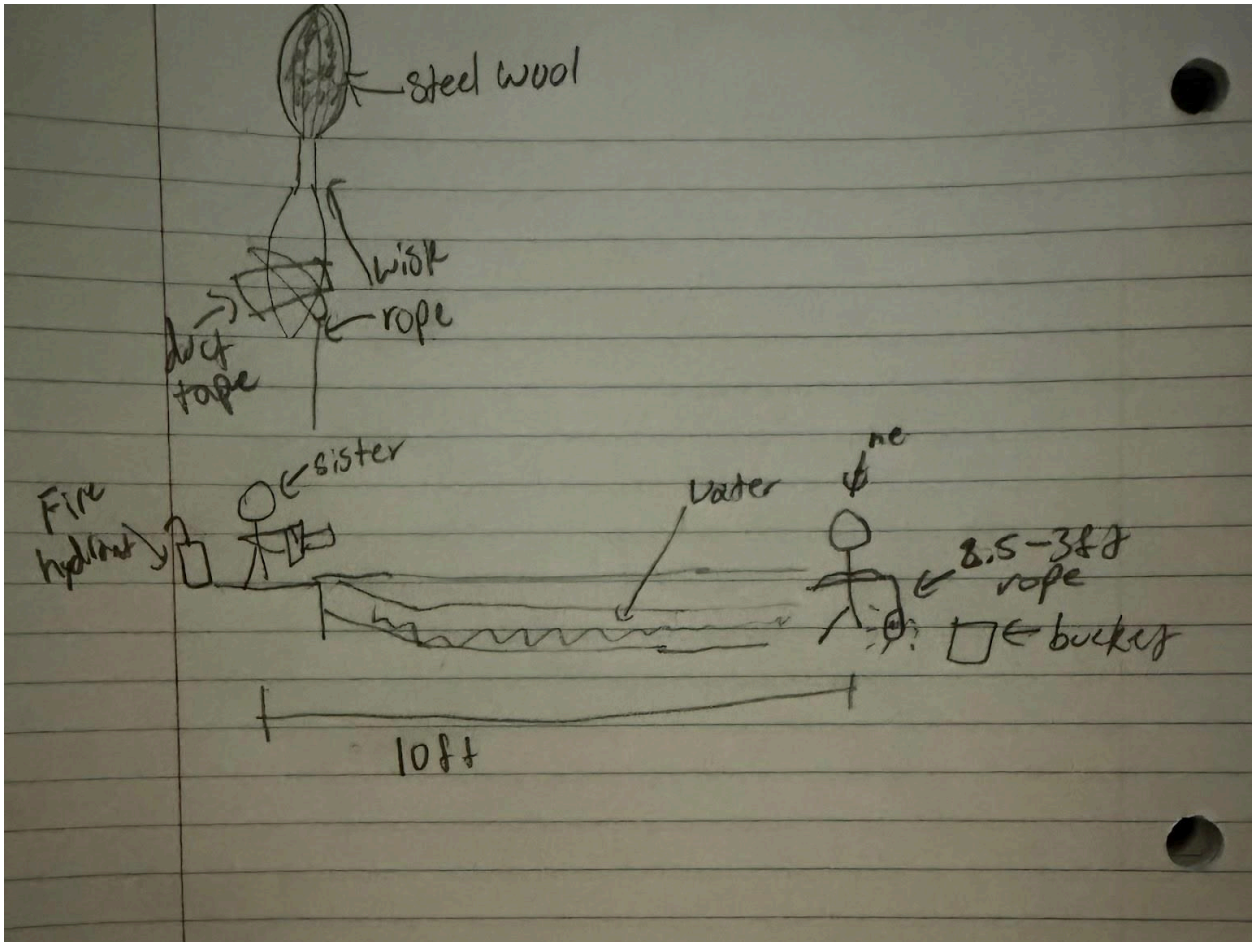
My sister assisted me with this by holding the camera and taking pictures of me making a figure eight with the steel wool. We were able to get a pretty good picture of the steel wool making a figure eight. Which is what we wanted to happen.

2. Apparatus and Experimental Setup

Steel wool was put in a whisk. Then we tied the whisk to a rope that was about 2.5-3 ft long. We tied a knot in the rope and also added some duct tape. After we lit the steel wool we started moving it in a figure eight pattern. We had the camera about 10 feet away from the steel wool and the camera was mounted to a tripod. My sister was able to control the camera while I was controlling the steel wool.

We also had some precautionary measures when we did this experiment. We had a bucket of water close by just in case we needed some. There was also a fire hydrant near my sister when he was holding the camera. The whisk was secured to the rope by using a knot and also adding some duct tape to it. This would allow the steel wool to not fall off while doing the experiment.

Figure 1. Experimental apparatus and camera arrangement.



[Insert a sketch showing the whisk containing steel wool, the rope, the figure-eight motion, the camera on its tripod, and the approximate 10-foot distance between the camera and subject.]

3. Fluid Phenomenon and Visualization Technique

Natural Convection is the fluid phenomenon that goes along with this experiment. While the steel wool is on fire it creates hot gas. This gas is lighter than the air around it so it can travel upwards. While this hot air is traveling upwards it will cause more air from around it to join the plume.

There are several things that affect how these sparks move. They can be affected by us moving the steel wool. Gravity can affect how they move and air resistance. The wind that day wasn't very strong so the air that was moving around the experiment wasn't traveling that fast. The highs outside that day were about 80 F or 26.7 Celsius. It was near the end of golden hour when we took this picture.

This picture was taken with the use of long exposure photography. Instead of seeing the steel wool at one point in time we are able to see the movement of the steel wool. Since we took this picture over the course of 8 seconds we are able to see the figure eight that the steel wool made. Most of this picture shows the movement of the hot particles and not the movement of the air. There is air that is moving upwards from this flame but we cannot see that in this picture.

4. Fluid Mechanics Calculations

There are three different values that can be found when trying to find the amount of motion of the fluid in this experiment. These values are Reynolds number, Grashof number and Rayleigh number. All three of these values help find out how much motion there is in the air surrounding the hot object.

Because we did not measure any of the temperatures or distance or velocity of the plume I will state what I am assuming. The high temperature that day was 80 F or 26.7 Celsius so I will use that. I will assume that the temperature of the plume is 100 C and that the width of the plume is .10 meters and the velocity of the plume is .50 m/s. These are just assumptions that I will use to try and calculate these values.

4.1 Assumed and Known Values

Parameter	Value	Description
(g)	(9.81{ m/s}^2)	Gravitational acceleration
(T_\infty)	(26.7 C)	Reported outdoor high, used as ambient reference
(T_p)	(100 C)	Assumed representative plume temperature
(\Delta T)	(73.3{ K})	Assumed temperature difference
(L)	(0.10{ m})	Assumed characteristic plume width
(U)	(0.50{ m/s})	Assumed characteristic plume velocity
(\beta)	(0.00297t{ K}^{-1})	Approximate thermal expansion coefficient of air

(\nu)	(1.95x10^{-5}{ m}^2/{s})	Approximate kinematic viscosity of air
(Pr)	(0.71)	Approximate Prandtl number of air

The air properties are evaluated at the estimated film temperature:
T_f={T_p+T_\infty}/{2}
T_f={373.15+299.82}/{2}
=336.49{ K}

Using the ideal-gas approximation for air:
{1}/{T_f}
={1}/{336.49}
=0.00297{ K}^{-1}

4.2 Reynolds Number

The Reynolds number compares inertial forces with viscous forces and is calculated using:
Re_L={UL}/{\nu}

Substituting the assumed values:
Re_L={(0.50)(0.10)}/{1.95x10^{-5}}

{Re_L= 2.56x10^3}

The Reynolds number we found would be high enough to say that for our air flow there are more inertial forces than viscous. We can't find what regime this experiment has because we do not know how fast the plume is traveling and it is constantly moving due to combustion and surrounding air flow.

4.3 Grashof Number

Grashof number will give you an understanding on the force of buoyancy versus viscous forces in a fluid. This can help describe flows of hot air traveling upwards from a fire, such as steel wool.

The equation is:
Gr_L={g\beta\Delta T L^3}/{\nu^2}

Substituting the assumed values:
Gr_L={(9.81)(0.00297)(73.3)(0.10)^3} /{(1.95x10^{-5})^2}
Gr_L= 5.62x10^6
]This estimated Grashof number suggests that buoyancy could have a meaningful influence on the movement of the heated air compared with viscous effects.

4.4 Rayleigh Number

The Rayleigh number combines the Grashof and Prandtl numbers and describes the relative importance of buoyancy-driven convection and thermal diffusion.

It is calculated using:
Ra_L=Gr_LPr

Substituting the estimated values:
Ra_L=(5.62x10^6)(0.71)
Ra_L=3.99x10^6

This estimated Rayleigh number further supports the possibility of buoyancy-driven natural convection in the heated air surrounding the burning steel wool.

4.5 Discussion on Results

There are three different numbers we can use to analyze our situation. Each of these will describe the air moving around our burning steel wool. Reynolds number will analyze how much inertia our flow has compared to viscosity. The Grashof number will show us if buoyancy or viscous force is greater and the Rayleigh number describes the diffusion of heat and buoyancy of air.

All of these values are just approximations since we did not collect the temperatures of the plume or width of our plume and speed of our air moving. Since we are assuming the velocity is 0.50m/s to find our Reynold number we can say that our results give a more in depth explanation for what may have been happening with the air around our fire. As you can see from our image we can't see our air moving however we know that buoyancy may have affected the motion of our air.

5. Space and Time

Our picture has 6000x4000 pixels. It was taken with a Canon EOS Rebel T7 and its 20mm focal length. Our camera was about 10 feet away from our flame. The Canon

has an approximately 22.3mm wide APS-C image sensor. We can use the width of our image sensor with our focal length and distance from our flame to approximate our Field Of View horizontally. We get about 3.4m.

To get our horizontal spacing we will divide our Field of View by

{Spatial scale}=3398{ mm}x6000{ pixels}
=0.566{ mm/pixel}

So one pixel will equal about 0.566 mm across our object of interest. Again this is only a rough estimation of how large the picture can resolve objects at. Depending on the focus, amount of contrast and if there is any motion or post-processing applied we could resolve more than this.

The exposure of our picture will determine our ability to see how the sparks were traveling. Our camera exposed for 8 seconds while capturing the sparks moving around in a figure eight. This allowed us to see the full motion of the sparks moving in the figure 8. However since we are able to see all of the motion within the time exposed we cannot tell exactly how fast each individual spark was going. We could take a picture with a smaller exposure time and only see part of the motion or use a larger exposure time and have bigger paths of light trail each other. With our 8 second exposure we were able to get a pretty good look at what the path looked like.

6. Photographic Method and Editing

Our picture was taken with a Canon EOS Rebel T7 DSLR with an 18-55 mm lens that was zoomed in to 20 mm. We were about 10 feet away from our object of interest. The camera was placed on a tripod so there was no movement from us when taking the picture.

Here are the settings on our camera:

- f-stop = f/16
- ISO = 100
- Exposure time = 8 seconds
- Zoomed in to 20 mm
- Picture dimensions 6000 x 4000

Our picture was taken near the end of golden hour which left some light in the background.

After taking our picture I edited it on Adobe Photoshop. There were a few things that I adjusted such as brightness, contrast, color and sharpness. I did this to give the

path of the light a more clean look and see what kind of changes the photo could have when editing. Both pictures are included to show you how we changed the picture when editing.



Figure 2. Unedited picture



Figure 3. Edited picture

7. Results

From our picture we can see the path that the burning steel wool traveled through. By using a long exposure time we were able to see what the full motion looked like when moving around in a figure 8 shape. The sparks from the burning steel wool gave us good contrast to the background so we could see the path it made. Also since we had our camera on a tripod our background stayed crisp and not blurred out.

Although our picture gave us information about what our steel wool did while it was falling it didn't allow us to know at what rate the sparks were falling. Because we are looking at all of the light that hit the camera for 8 seconds we can't say with certainty what happened during that time period. We also don't know what our velocity was moving in the air or the temp of the air. All we can tell from our picture is what the path of the steel wool took while burning.

There are many more things that could be done with this project if we wanted to learn more about how hot air rises. Maybe using different exposure times and camera angles. We could also try to find a better way to visualize our plume of air rising. But I think that our picture helped explain the path of light while falling.

References

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