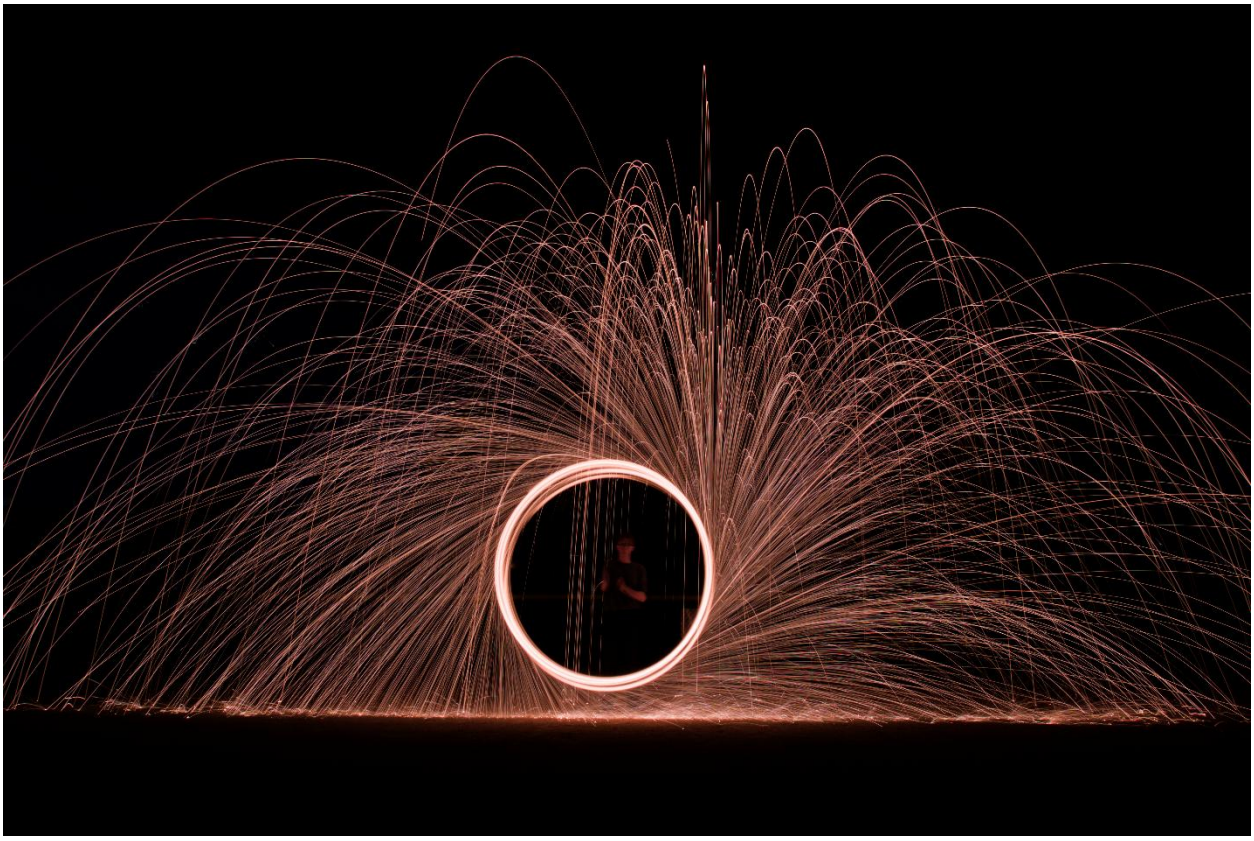
Portal of Sparks



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MCEN 5151: Flow Visualization
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Introduction

Portal of Sparks was created for the Flow Visualization class at CU Boulder for the Team Second Assignment. This class is where art meets science and focuses on showing and explaining the physics behind flow phenomena. The goal of this photo was to capture a long exposure of movement. I wanted to experiment with long exposures and also experiment with fire. A DSLR camera was used to take the image and help with the image was received from classmates Joy Wakimura and Joshua Keller.

Experiment Setup

For this experiment, a whisk was purchased from Goodwill, and steel wool was purchased from McGuckin's. The shot was taken on the dirt part of a baseball field and the team made sure there was nothing flammable nearby. The team also wore appropriate safety gear and had a fire extinguisher and a bucket of water. The photo was taken just after dark with an exposure of 5 seconds. The camera was set up on a 4.5 foot tall tripod placed 25 feet from the fire circle.

The whisk was attached to the end of a piece of paracord which was 3 feet long, and the steel wool was put inside of the whisk. Joshua stood in the center of where we wanted the circle and held onto the paracord. A 9V battery was then used to light the steel wool on fire. Once the whisk was on fire, Joshua swung the whisk around in a consistent radius circle. The airflow helped accelerate the steel wool burning and the sparks from the steel wool flew off as the whisk swung around. The final image had an exposure length of 5 seconds and was taken once the sky was fully dark.

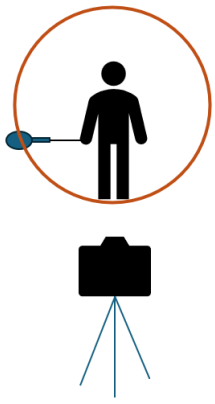


Figure 1: Experiment Setup Diagram

Table 1: Equipment list

Equipment	**Details**
Camera	DSLR
Tripod	Benro TSL08AN00
Whisk	Whisk with loop on handle
Paracord	3 feet
Steel Wool	Extra fine, grade #0000
Battery	9V
Water	A 5 gal bucket of water
Fire extinguisher/fire blanket	Type BC
Protective clothing	Long sleeves, safety glasses, boots, gloves

Flow

The fire circle launched sparks as the whisk was spun around. These sparks left the circle on a tangential path and eventually fell to the ground. The fire circle had a radius of 3 feet, and the tallest spark reached 15 feet above the center of the circle. Using kinematic equations, the angular velocity can be found [1].

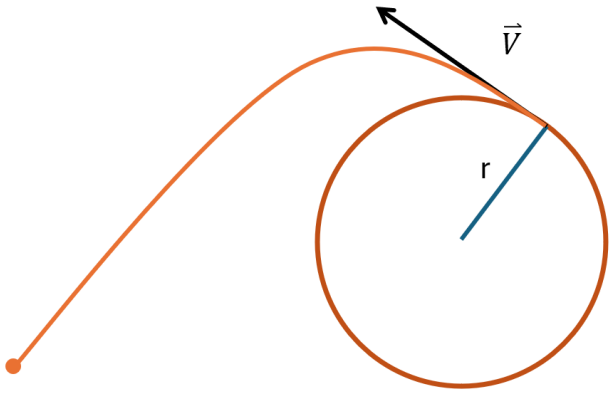


Figure 2: Particle trajectory and kinematics

Equation 1: $V_f^2 = V_i^2 + 2ad$

V_f is equal to zero at the highest point the spark reaches. Acceleration due to gravity is 32.2 ft/sec^2 and the distance is 15 feet above the center of the circle. Plugging in the values to equation 1 gives us:

$$0 = V_i^2 + 2\left(-32.2\frac{ft}{s^2}\right)(15\ ft)$$

$$V_i = 31.1\frac{ft}{s}$$

The angular velocity can be found by using equation 2 and the radius of the circle [2].

Equation 2: $\omega = \frac{V_i}{r}$

$$\omega = \frac{31.1\frac{ft}{s}}{3\ ft} = 10\frac{rad}{s} = 1.6\ Hz$$

The time it takes for the highest particle to fall can be found using equations 3 and 4. Equation 3 finds the time it takes the particle to travel to the highest position. Equation 4 finds the time it takes the particle to fall to the ground from the highest position. The highest particle reached a total height of 18 feet above the ground before falling again. The time it took the particle to reach this height and then hit the ground was just over 2 seconds.

Equation 3: $V_f = V_i + at_1$

$$0 = 31.1\frac{ft}{s} + \left(-32.2\frac{ft}{s^2} * t_1\right)$$

$$t = 0.966 \text{ sec}$$

Equation 4: $d_f = d_i + V_i t + \frac{1}{2}at_2^2$

$$0 = 18\ ft + 0 + \frac{1}{2}\left(-32.2\frac{ft}{s^2}\right)t_2^2$$

$$t_2 = 1.06 \text{ sec}$$

$$t_{total} = 2.02\ sec$$

To describe the behavior of the sparks the Tachikawa number can be used. It is defined as the ratio of aerodynamic force to gravitational force on a windborne particle [3]. The Tachikawa number is dimensionless and is used in wind engineering.

Equation 5: $Ta = \frac{\rho_a A U^2}{2mg}$

Table 2: Tachikawa number variables and values

Variable	**Value**
Density of air: ρ_a	0.07631 (lbm/ft^3) at 65º [4]
Particle surface area: A	1/9216 (ft^2)
Wind speed: U	4.4 (ft/s)
Mass of particle: m	0.00055 (lbm)
Gravity: g	32.2 (ft/s^2)

The density of air was calculated at 65 º and an estimated wind speed of 3 mph was used. The surface area of the particles were assumed to be (1/8 in)^2 and the mass of the particles were estimated to be a quarter gram.

$$Ta = \frac{\left(0.0156\frac{lbm}{ft^3}\right)\left(\frac{1}{9216}ft^2\right)\left(4.4\frac{ft}{s}\right)^2}{2(0.00055\ lbm)\left(32.2\frac{ft}{s^2}\right)} = 0.00093$$

Plugging in all of the values gives a Tachikawa number of 0.00093. This number is much smaller than 1 meaning that the gravitational forces are much stronger than the aerodynamic forces, so the effect of air resistance on the sparks' travel is negligible. The gravitational forces pull the sparks down to the ground in parabolic paths where you can see them explode on impact in the image.

The temporal resolution of this image is time-averaged because it is a long exposure. This means it is not time-resolved, and you can see the motion of the particles flying through the air. The spatial resolution of the image is 0.087 inches per pixel and the smallest part of the flow, which were the spark streaks, were 0.44 inches. This was calculated using the height of my teammate as a reference.

$$823\ pixels = 6\ ft$$

$$1\ pixel = 0.087\ in$$

$$5\ pixels = 0.44\ in$$

Visualization Technique

The visualization technique used in this shot was particle tracking with a long exposure. The long exposure allowed the movement of the particles to be followed in a single image. The particles themselves were small bits of burning steel wool. The steel wool burned for approximately 20 seconds before going out. I played with different lengths of exposures and settled on 5 seconds because it allowed for a full image of particles but was short enough you can still see individual particle paths.

Photography and Post Processing

The photo was shot using a DSLR camera with the specifications shown in Table 3.

Table 3: Camera specifications

Camera Model	Nikon D7500
Lens	AF-S NIKKOR 24-70mm 1:2.8G ED
Focal Lenth	24 mm
ISO	160
Shutter Speed	5 seconds
Aperture	f 10

Field of View	53.0º diagonal
Original Dimensions	5600 x 3728 pixels
Edited Dimensions	5600 x 3728 pixels
Distance from fire circle	25 feet

The image was taken approximately 25 feet away from the fire circle. The scene was almost completely dark except for a few streetlights in the background. The camera was set up on a 4.5 foot tall tripod so the image would be still for the long exposure. The camera settings were used to balance the exposure and provide good visual quality. The image was postprocessed in Darktable to create more contrast between the black background and the bright fire. The colors were adjusted slightly to bring out the vibrant color of the fire. The image was not cropped but retouch was used to remove the streetlights. A before and after image is shown in Figure 3. Note, the final image should be viewed on the flowvis.org website to see a higher quality image.



Figure 3: Original image on left and edited image on right

Conclusion

Portal of Sparks reveals the beauty of sparks and fire. The shot also reveals the tangent trajectory of particles being swung in a circle and then released. I love the contrast between the bright sparks and the dark black background. I also love being able to see the trajectories of the flying particles. I wonder what other effects one could make with this setup. I'm very happy with the shot, both with flow physics and aesthetics. However, I would like to have been able to capture the full flight of the particles and not have them cut off on the edges of the photo. To continue this shot, I would like to experiment with other movements like walking backwards to create a spiral.

References

[1] J. Hanna. “Kinematic equations.” PASCO scientific. https://www.pasco.com/resources/articles/kinematic-equations (accessed Nov 1, 2026).

[2] M. D. Shuster. "The kinematic equation for the rotation vector," *IEEE Transactions on Aerospace and Electronic Systems*, vol. 29, no. 1, pp. 263-267, Jan. 1993, doi: 10.1109/7.249140.

[3] J.D. Holmes, C.J. Baker, and Y. Tamura. “Tachikawa number: A proposal,” *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 94, no. 1, pp. 41-47, Jan. 2006, doi: 10.1016/j.jweia.2005.10.004.

[4] “Air Density, Specific Weight, and Thermal Expansion Coefficients at Varying Temperatures and Pressures.” The Engineering ToolBox. https://www.engineeringtoolbox.com/air-density-specific-weight-d_600.html (accessed Nov 1, 2026).