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MCEN 5151
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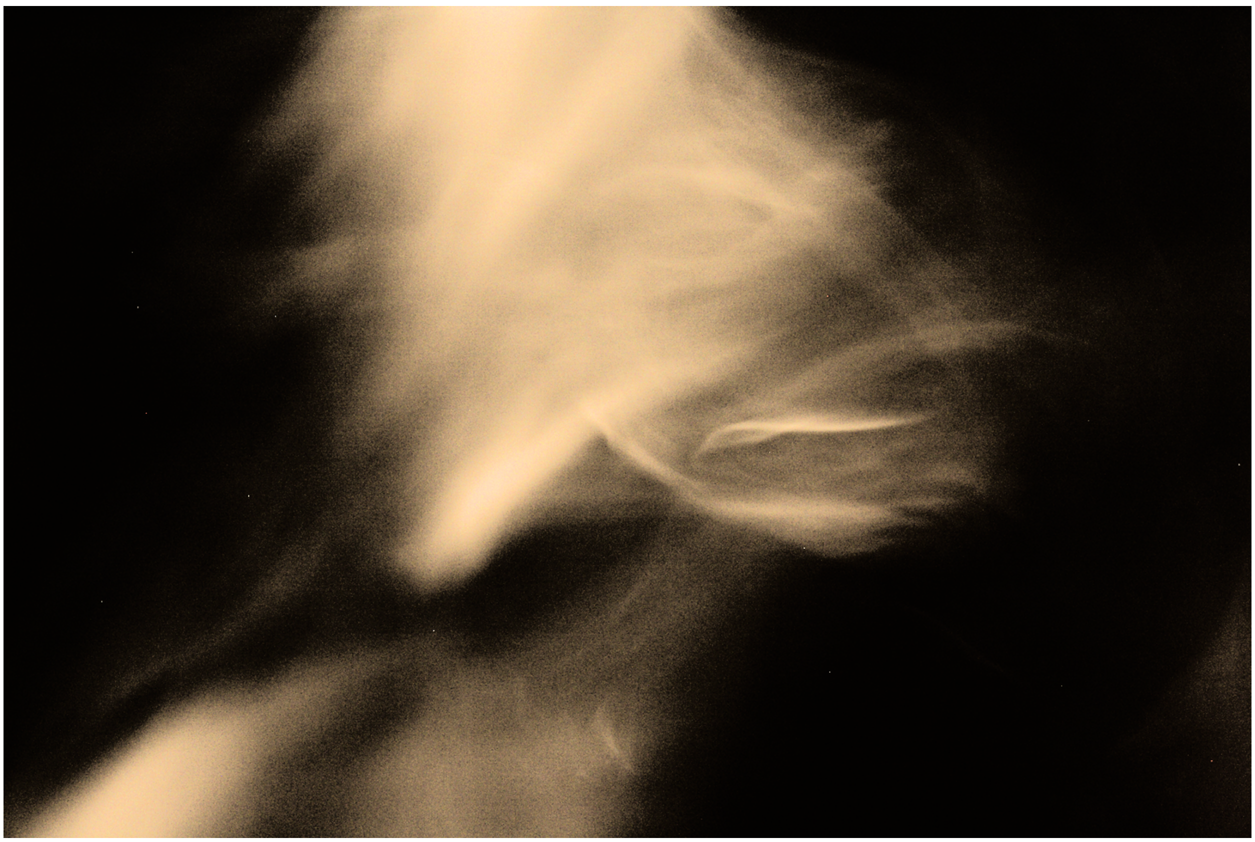
Get Wet/IV 1

Plume of Smoke



Introduction

The objective of this image was to get more acclimated to my camera equipment and capture an interesting fluid flow. For my first image, I opted to capture smoke rising from a recently extinguished candle. Through this image, I was hoping to capture the effects of airflow in the room as well as the buoyant forces in effect with heated air.

Apparatus

The apparatus for this image was quite simple in practice. A sketch of the setup is provided below.

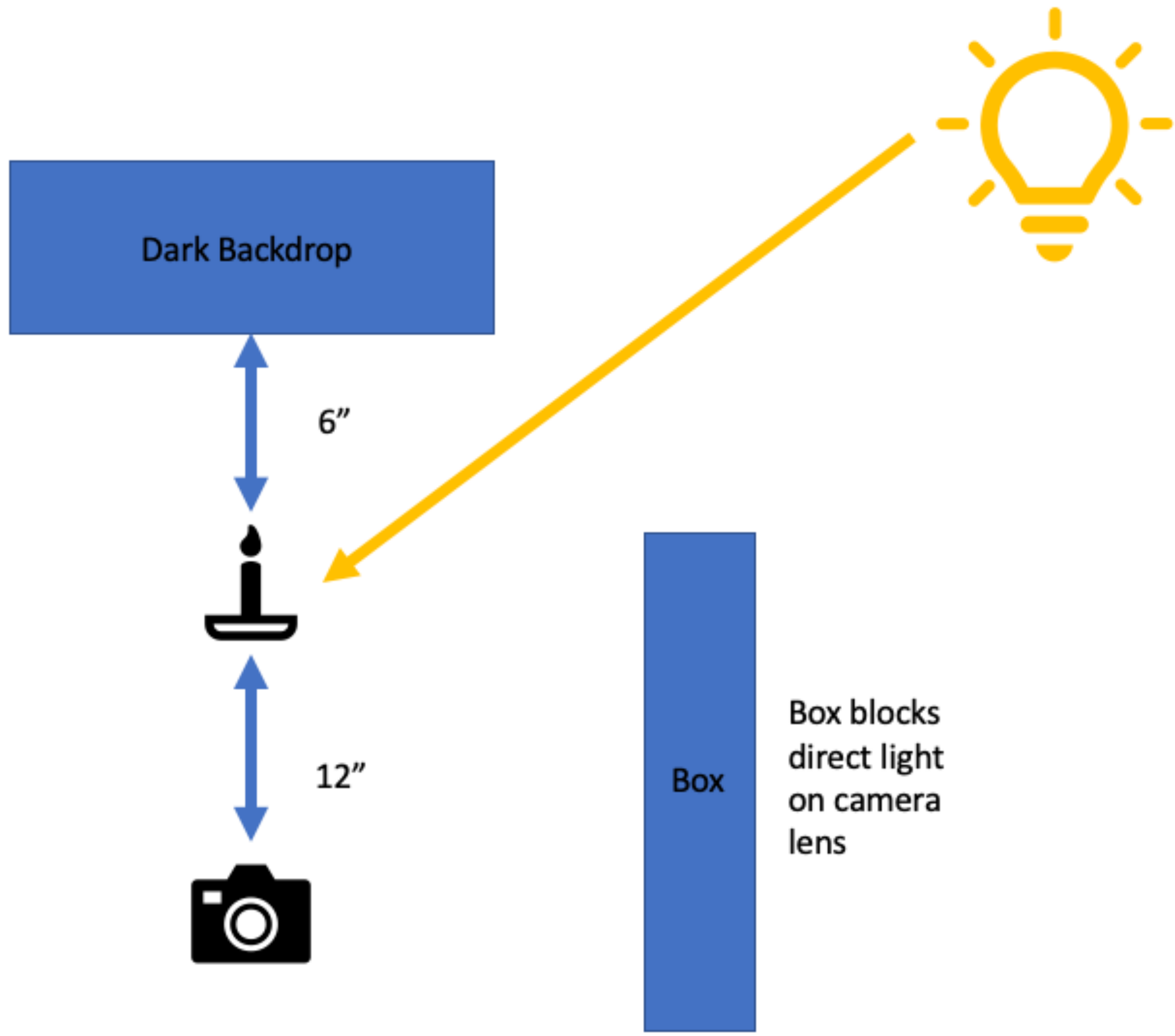


Figure 1: Apparatus

A candle was set up 6 inches from the background, a dark grey bedsheet. This dark background was necessary to allow the flow to be put against a pure black background in post processing. The camera was positioned 12 inches from the candle itself, aimed 6 inches above the candle wick and 4 inches above the rim of the candle. The light source, a lamp, was positioned at roughly 120-140 degrees from the camera position. The box was used to prevent direct light from impinging on the camera lens, which prevented glare in the photos. The candle was lit, then subsequently extinguished once the candle burned on its own for 5 to 10 seconds. In the following 5 to 10 seconds the images were taken, up until the candle stopped producing enough smoke to be visible.

Flow Physics

The main flow phenomenon seen in this image is the presence of buoyancy-driven flow, or natural convection. The primary nondimensional coefficient associated with this type of flow is the Rayleigh number, which defines the ratio of the destabilizing effect of buoyant forces to the stabilizing effect of viscosity (Kundu and Cohen 2008). The Rayleigh number is defined as follows:

$$Ra = \frac{g\alpha\Gamma d^4}{\kappa\nu} = \frac{9.81 * 3.43 \times 10^{-3} * 819.67 * 0.1524^4}{21 \times 10^{-6} * 15.06 \times 10^{-6}} = 4.70 \times 10^7$$

Where g is gravitational acceleration, alpha is the coefficient of thermal expansion, gamma is the vertical temperature gradient, d is the depth of the layer, kappa is thermal diffusivity, and nu is the kinematic viscosity. The critical Rayleigh number, the point where transition to turbulent flow begins, is roughly 10^9 (Bahrami), orders of magnitude larger than the calculated result. This shows that the convective fluid flow is still laminar as this photograph was taken, which is highlighted by the very clear laminar layers in the middle of the picture. It is difficult to see the laminar nature of the other parts of the image, however this could be due to the orientation of the laminae when the picture was taken.

This calculation represents a conservative estimate for the Rayleigh number associated with the flow, meaning the values were chosen to represent an upper bound for the true Rayleigh number.

Visualization Technique

The technique for this image is very simplistic and easily repeatable. The smoke from the extinguished candle was used to visualize the motion of the air above the candle. The candle itself is the kiwi passionfruit scent produced by White Barn.

The lighting of this shot was also very straightforward. This experiment was done with a single lamp as the light source in an otherwise dark room. The lampshade was removed so the light, a

60 Watt incandescent bulb, would be more powerful on the smoke I was trying to capture. The lightbulb itself was positioned 12 inches off the ground, the height of the lamp. Additionally, as mentioned before, the light source was placed roughly 120 degrees counterclockwise from the position of the camera. Camera flash was not used when taking this photograph.

Photographic Technique

This image was taken using a Canon EOS DIGITAL REBEL XS with an 18-55mm lens. The properties for my final image are tabulated below.

Image Property	Value
Shutter Speed	1/6 sec
Focal Length	55 mm
ISO	1600
Aperture	f/8
Pixels	3888 x 2592

Table 1: Photograph Specifications

The lens itself was 12 inches from the center of the candle and 6 inches off the ground, roughly in the same horizontal plane as the area of smoke that was photographed. The structures were very small (on the order of inches), so the camera zoom was fully exploited to get a large image of the frame. The field of view of the camera at the distance I photographed was 7.85 inches in width and 5.24 inches in height.

The environment was relatively dim, so the ISO setting needed to be set very high in order to capture the image. This is also why the shutter speed is so slow. The camera was trying to capture as much light as possible, and due to aperture priority mode being used for this photo, the shutter speed was automatically selected. This could be another factor as to why more laminar flow is not seen in the final image.

Finally, Dark Table was used to increase the contrast between the smoke and the background of the photo. The RGB curve specifically was adjusted to improve this aspect of the photograph.

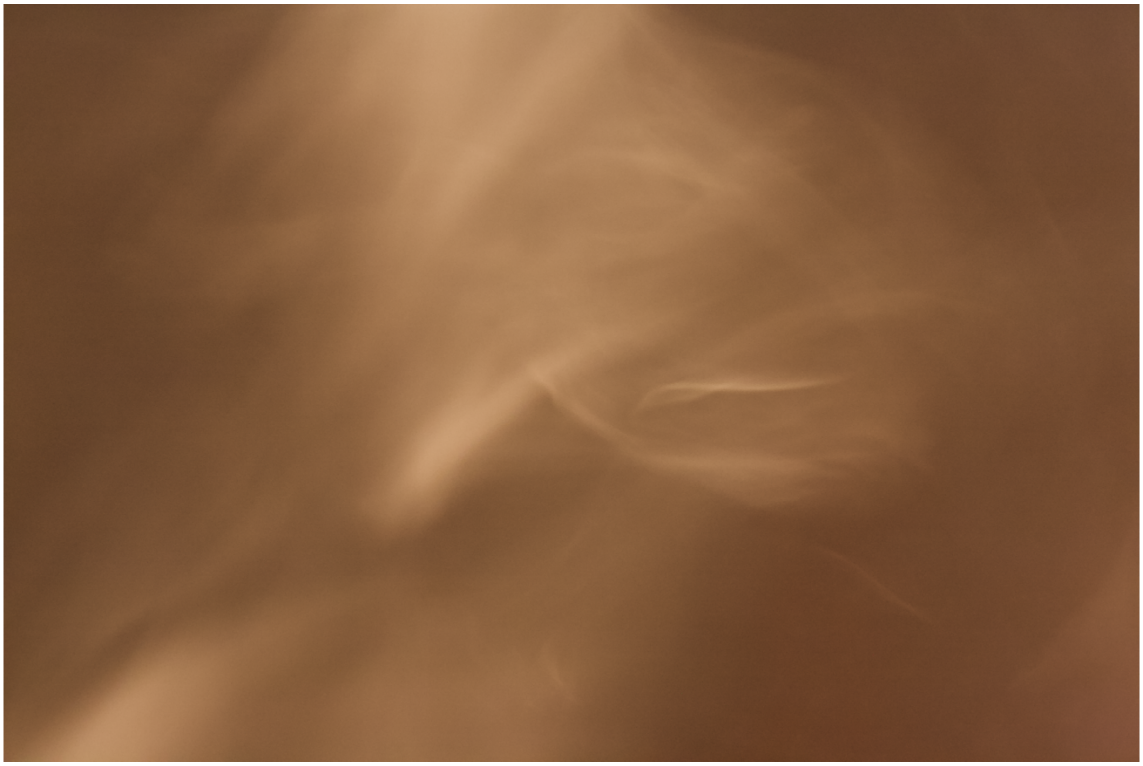


Figure 2: Original Image

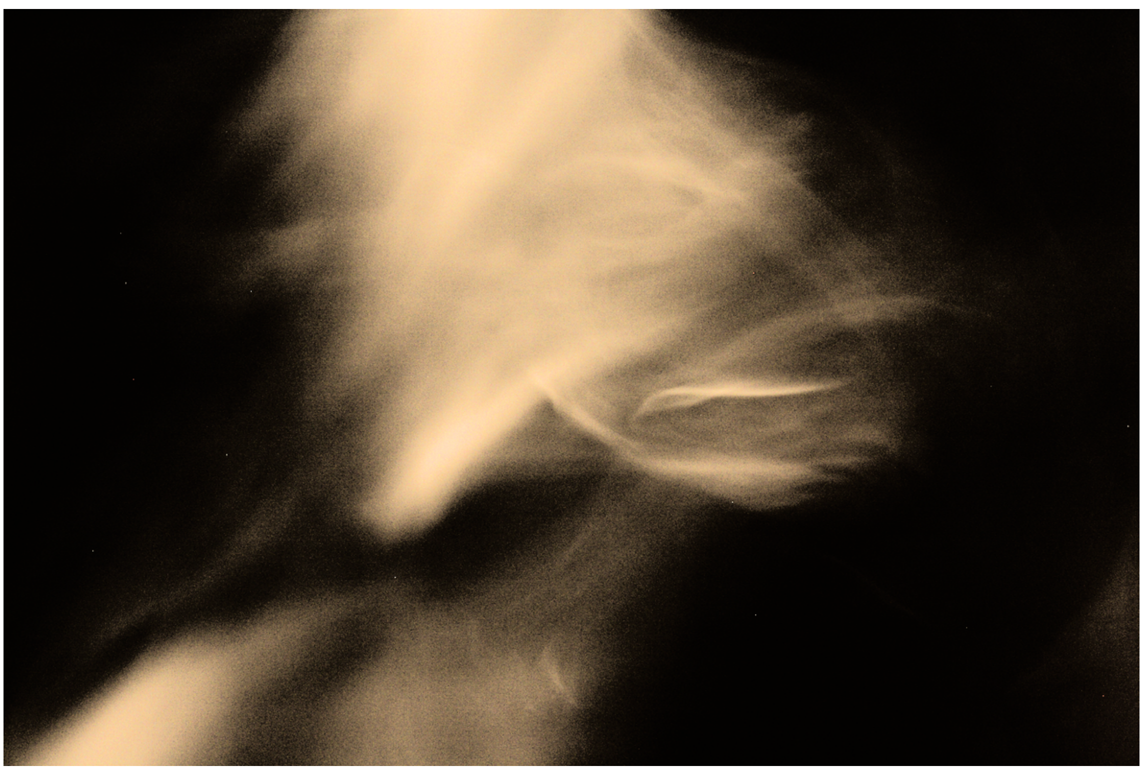


Figure 3: Final, edited image

Conclusion

This image captures a lot about the complex fluid flows that happen around us every day, though we typically can't see it. I think the framing of the smoke against the pitch-black background really emphasizes and keeps your eye glued to the flow itself, which I think improves the image greatly. I do wish I was able to capture more of the laminar nature of the flow, as it only appears in one part of this image. I think it has to do with the sheer amount of smoke produced by the candle. If I were to repeat this experiment again, I would use incense instead of a candle so I could more clearly see the path of the smoke. Overall, however, I think this is a good visualization of the phenomenon I wanted to capture, and I am happy with the image I produced.

References

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