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MCEN 4151

Get Wet Assignment

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Background

The purpose of the first individual assignment for this class was to "Get our Feet Wet" (Ionized?). The main overall goal was to gain a basic understanding of photography techniques and camera operation, while simultaneously capturing flow phenomena that may seem interesting to the individual.

The idea for this assignment came from my fellow rocket friend and roommate, Sam. Upon telling him about this course, he suggested that we should take some welding photos in the Physics Trades and Teaching Lab (PTTL) to capture the stunning weld arcs generated by welding. I liked this idea, and soon thereafter scheduled a few hours of our time to take these photos. I immediately decided on TIG (Tungsten Inert Gas) arc welding, as this type of welding generates a stunningly bright and clear arc. Other types of welding, such as MIG (Metal Inert Gas) or SMAW (Shielded Metal Arc Welding) generate considerable smoke and metal sputter. These welding types are much "dirtier" than TIG; the smoke hides any clear sight of the arc, and the molten metal sputter can easily damage camera equipment.

Sam was the designated welder for the assignment. Almost all the welding photographs I captured had him operating the welding equipment. Paul Wingrove from the CU Physics Department gave us access to the PTTL lab and all associated welding equipment and PPE (Protective Personal Equipment).

The hope of this first assignment was to capture clear up-close photographs of TIG arcs. The first few welding photographs were either out of focus, overexposed, or simply not close enough. The quality of the photographs rapidly improved as I adjusted my camera settings and got used to operating my camera while I was covered in welding PPE.

The Physics Behind the Flow

The flow apparatus used for this assignment was a TIG welding machine. This apparatus includes several components, all of which are outlined in figure 1 below.

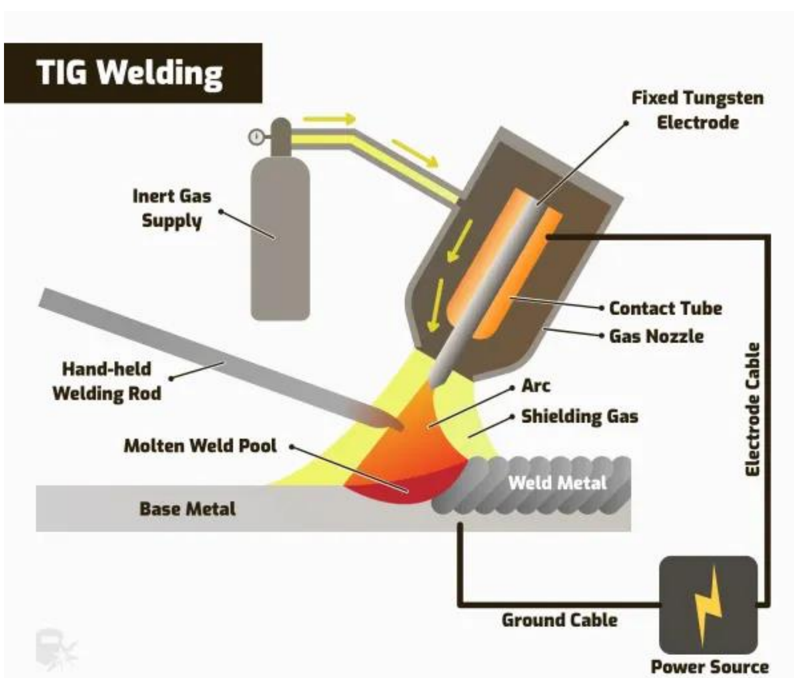

Figure 1: How TIG welding works

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What is a TIG welder? How does it work?

The technical name for TIG welding is GTAW – Gas Tungsten Arc Welding. This is a welding process that melts and joins metals by heating them with an arc generated between a non-consumable tungsten electrode and the weld metal[1], as shown in figure 1 above. A direct current (DC) power supply is used to generate large amounts of electrical energy. This electrical energy in turn produces immense amounts of heat in the surrounding air and metal as it flows from the electrode to the weld metal. A shielding gas, commonly argon, is released from the pink ceramic cup while the user is welding. This shielding gas is needed to prevent the weld metal and the electrode from oxidizing by the oxygen in the air. An inert gas blanket is formed in and around the arc, and effectively prevents any oxidation from damaging the weld.

Plasma is also generated as a byproduct of the massive electrical potential generated. The surrounding shielding gas, in this case argon, undergoes dielectric breakdown when exposed to great electric fields. This causes the argon gas to split apart into electrons and argon nuclei (ionization) and allows it to become conductive. The plasma then conducts the rest of the electricity and heat down to the weld metal and heats it up extremely rapidly. It usually takes no more than a few seconds to melt the metal you're welding.

You can see a plasma impinging on a stainless steel pipe in my featured photo. See how it curves in and holds a steady shape rather than spreading out erratically like a traditional flame; these are electromagnetic forces at play.

[1] Kou, Sindo. *Welding Metallurgy*. Wiley, 2021.

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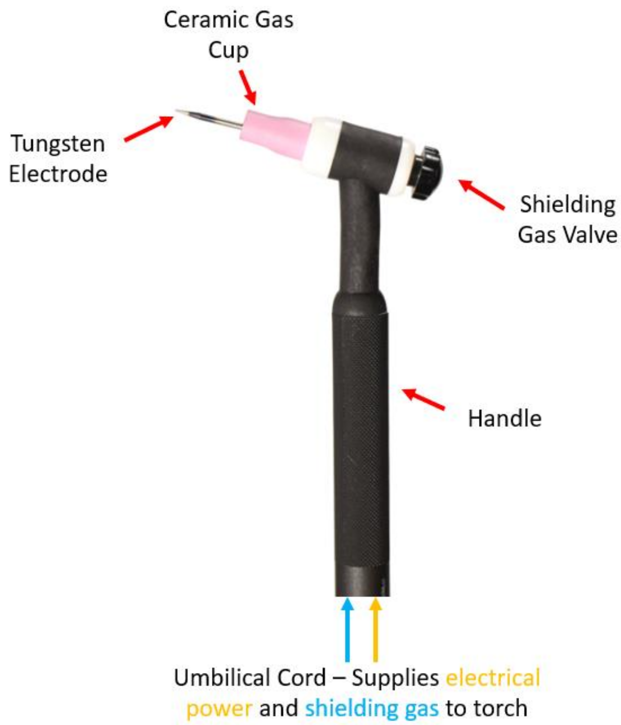

Figure 2: Example of a TIG torch. Annotated by myself.

Photo credit: Everlast Generators. https://www.everlastgenerators.com/product/nova-26-rigid-neck-tig-torch-125ft-25-series-dinse

Now, equipment specifics. The welder (Sam) holds the TIG "torch", which is a handheld device that consists of the gas nozzle and electrode. I made a figure that outlines the composition hand-held torch in figure 2 above.

The tungsten electrode is where the arc is generated. The shielding gas flows out of the hollow pink alumina ceramic cup and protects the electrode and base metal from any oxidation. Some torches have a manual valve to meter the shielding gas flow to a desired level. Below the handle, (not directly shown in the figure) is an umbilical cord that carries electrical energy through a copper conductor and shielding gas through a gas hose.

This manual (and very involved) aspect of TIG welding makes it very precise, and often leads to extremely beautiful, high-quality results. However, it is a slow process that requires extensive skill to master.

Unfortunately, plasmas cannot be modeled and analyzed in a similar way to other common flows. Plasmas are indeed influenced by common fluid forces like gravity, viscosity, momentum, etc. However, these forces are not dominant in the behavior of the flow. Plasmas are influenced mostly by electric and magnetic fields. I could not find any simplifying analytical models to describe what was happening in my Get Wet assignment.

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Flow Visualization Technique

Weld arcs produce immense amounts of light. That is to say, the flow was emissive and did not need any external lighting to effectively visualize.

Why?

Well, I mentioned earlier that the massive quantities of electrical current causes the surrounding argon gas to break down into plasma. When atoms in a gas are energized, they become excited. This atomic excitation causes electrons in the argon gas to jump back and forth between atomic energy levels. When an electron in the argon jumps down from a high energy level to a lower energy level (or recombines from ions back into an atom), it releases a photon. This is what gives the argon its characteristic purple-blue color; this is the atomic emission spectra of argon gas. So, what you're effectively seeing is energized atoms releasing all their accumulated energy in the form of visible photons, light!

Safety Precautions and Other Considerations

This spectacle of heat and color comes at a cost. Weld arcs do not only generate immense amounts of visible light, but also generate considerable amounts of heat and UV radiation. As such, wearing the appropriate PPE is a *requirement* for any type of welding. This equipment usually consists of the following:

1) Welding hood
2) Welding gloves
3) Long Sleeve FR (Fire Resistant) Coveralls

This PPE can present a challenge to a keen welding photographer. Thick Kevlar gloves make handling of the camera awkward and difficult. Make sure to be familiar with the operation of your camera before welding on! I suggest practicing operating your camera with these gloves for a few minutes to get familiarized.

The biggest challenge I encountered was taking photographs while I had a welding hood on. The welding hood is large, clunky, and obscures your view as soon as you lower it into position. Most welding hoods nowadays have auto-darkening lenses. These auto-darkening lenses allow you to clearly see through your weld hood whenever light levels around you are moderate. However, as soon as the lens detects a significant source of light (like that of a weld arc!), it instantly darkens to protect your eyes from the UV rays and sun-like light produced by the arc. Peering through the viewfinder while my view was obstructed and darkened was very difficult. I was struggling to keep shots in frame and focused even after getting a clear shot of the weld through the viewfinder. This was likely because the viewfinder crosshairs were very difficult to see under the bright weld arc and darkness of the hood.

Photographic Techniques

The camera setup was entirely manual. I knew that the weld arc would be extremely bright and would likely overexpose the camera, so I started off with low ISO values (100-200) and the fastest shutter speeds my camera could manage (1/3000 – 1/4000). The photographs were overexposed at the higher values (ISO 200, shutter 1/3000), so I stuck to the lowest values possible. I was unaware at the time, but I operated the camera in the mirror-down mode; this only permitted me to see what I was shooting through the viewfinder, but also protected the CMOS sensor from constant exposure to high-intensity UV and light rays. In hindsight, this was the right choice. I was rather worried about UV exposure damaging my camera, so I installed an Amazon Basics UV filter in front of the lens for extra reassurance. This UV filter did add a bit of glare and reflection but was not very noticeable in most of the photos captured.

I positioned myself as close as comfortably possible to Sam and his TIG torch. I managed to get about a foot away from the weld arc and captured most of the pictures at this distance. A little bit of zoom from the macro lens helped keep the weld in frame in the viewfinder. However, the field of view was much larger than desired; I didn't know that I was using a macro lens at the time.

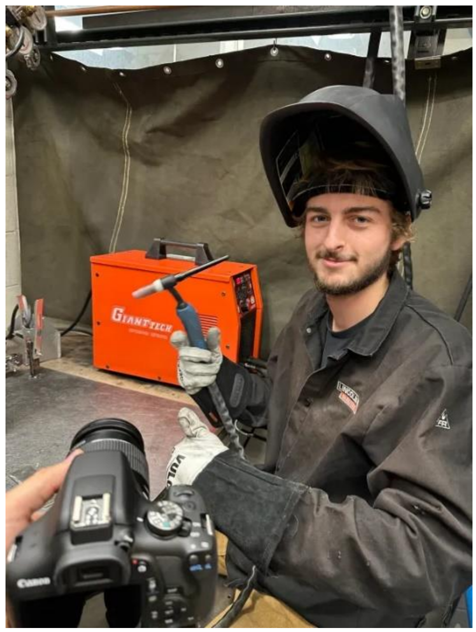

Figure 3 – Sam posing with his TIG torch and our equipment setup.

The camera settings are outlined in table 1, shown below.

Setting	Value
Camera	Canon EOS T7 Rebel DSLR
Final Image Width	Digital, 4000x6000
Lens	18-55mm Macro Lens
Focal Length	55mm
Focus Distance	0.35m
Aperture	f/5.6
Exposure	1/4000
ISO	100

Table 1: Camera Settings

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I decided not to use any image post processing, due to a lack of knowledge in the field. I was also very satisfied with the quality of the images produced; they exceeded my initial expectations.

Image and Comments

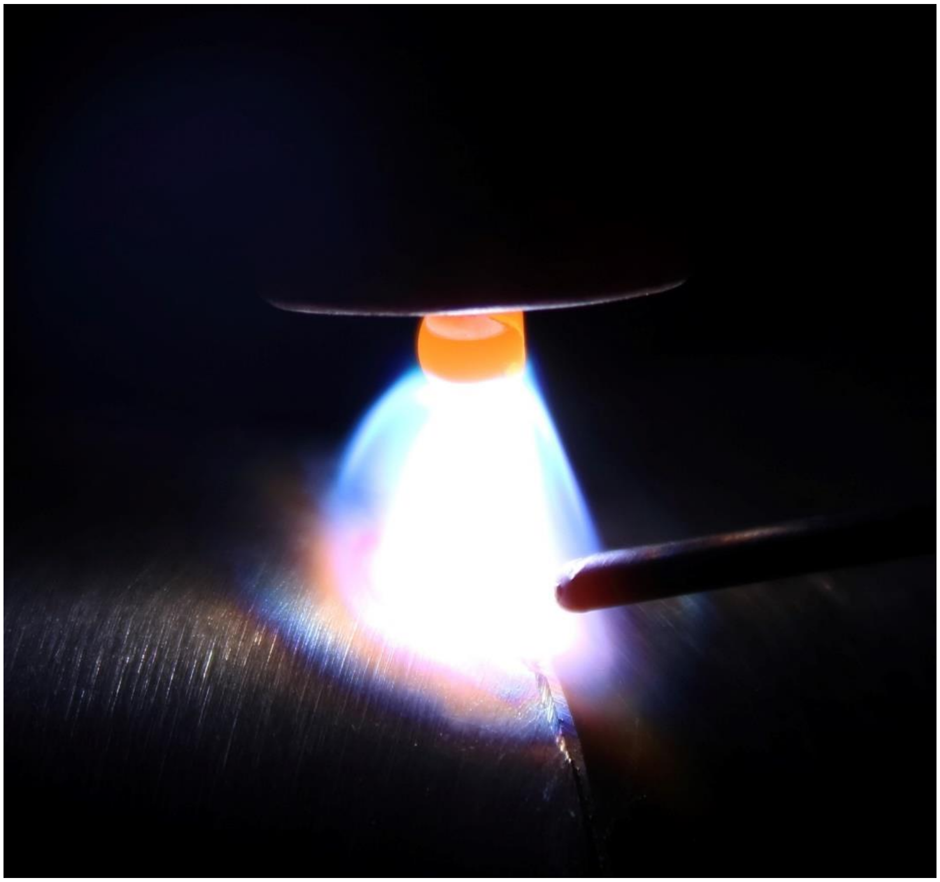

Figure 4: Final, cropped photograph.

The image above reveals a TIG weld arc in all its glory. I can safely say that I did fulfill my intended outcome. I really like the spectra of colors generated by the plasma emitted by the torch, and the rainbow-colored oxide film forming on the stainless steel weldment. The melting tungsten electrode adds additional color and intensity to the image, emphasizing the stunning amounts of heat generated by this process. The arc is clear and focused but is rather overexposed.

I did not like that most of the center of the arc was still overexposed. I did realize that my f stop was perhaps set too low (large aperture) to effectively drown out most of the intensity of the arc. I should have gone with a higher f number to reduce the overexposure seen. Perhaps the usage of a neutral density filter would have also helped make the plasma appear more translucent and give better insight into the flow phenomena at play. Perhaps some post-processing could help drown out the intensity of the arc, and make it appear more translucent.

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References

https://weldguru.com/tig-welding/

Kou, Sindo. *Welding Metallurgy*. Wiley, 2021.