Flowing Gas
CO2 Laser

Mk. III

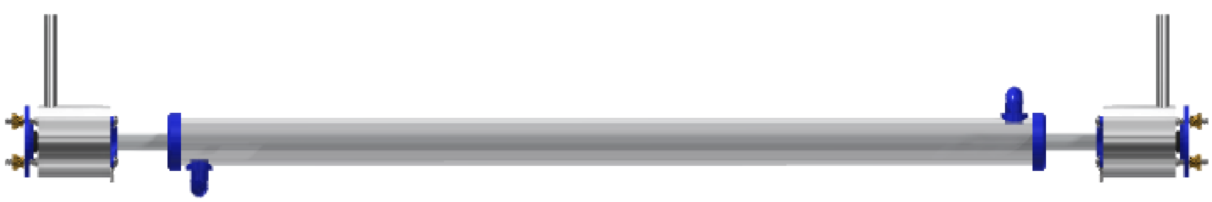


Table of Contents

Running Operation Notes

9/26/18 - First Test: The laser worked in the sense that it lased. However, the output was extremely minute and completely unusable. I detected lasing with a Peltier thermocouple chip connected to a multimeter, placed about 8 inches from the output end of the laser. Before turning anything on I allowed the chip to sit and monitored the multimeter to ensure any temperature difference from handing the chip with my warm hands had dissipated. I then evacuated the tube and turned on the power supply to create the plasma discharge I monitored the multimeter to ensure the detector was not affected by the ambient heat from the plasma discharge. I then slowly introduced the gas mixture into the laser tube and the multimeter spiked to .03 volts and remained at this voltage for the next minute as the laser was kept running. Although minute, this multimeter voltage spike does suggest lasing occurred.

The gas mixture I used was not measured, it was approximated. It consisted of approximately 10% CO2 (from a bicycle tire inflator cartridge) and 90% Helium (from a party balloon filler; the helium gas itself was a mixture of 80% helium and 20% air). Water cooling was turned on and the power supply output was AC rather than DC. I will not purchase the parts for the bridge rectifier circuit to convert AC to pulsed DC until I save up more money over winter break.

I believe adding nitrogen and precisely measuring the amounts of gases will increase performance. Nitrogen may be able to be obtained from a canister used for aerating draft beers. The gas amount can be measured using the procedure described towards the end of these plans.

Summary of Contents

This document contains plans for construction and detailed descriptions for safety and operation. This is not a research project, but merely a reference for me to use when constructing and operating the laser. Also, I hope to reference this material when completing future projects as it contains a lot of information about things other than a laser itself such as high voltage power supplies and safety.

The purpose of constructing this laser is simple: to learn about lasers. I have no practical use for this laser as I already have a small CO2 laser cutter. I believe the best way to learn about something is to build it and that is the sole purpose of this project.

Improvements and Upgrades

1. Increased modularity of the laser. The laser is divided into subsystems and subassemblies that can be easily removed and installed using ring clamps. This allows for a subsystem to be swapped with another for the sake of experimentation or repair.
2. The first version was connected directly to the AC output of the neon sign transformer. A bridge rectifier circuit has been designed to deliver DC to the laser tube. Pumping the laser with a DC output will increase the output power.
3. In previous versions, the orifice of the valve connected between the vacuum pump and laser tube was smaller than the orifice of the valve connected between the gas supply and the laser tube. This valve setup essentially choked the laser, as the maximum volume of gas traveling into the laser exceeded that of gas displaced out through the smaller valve by the vacuum pump. This has been addressed as valve size and type was more carefully considered during the design.
4. Increased the number of adjustment screws per end of the laser from three screws arranged in a circular pattern to four screws arranged in a square pattern. This will allow for easier optics adjustment and alignment.
5. A vacuum gauge has been added to aid in monitoring and controlling the pressure inside the laser tube.
6. In previous laser tube versions, the glass discharge tube was permanently attached to the cooling jacket and the optics mounts with epoxy resin. For this version, two mechanisms were designed to create easily removable and replaceable seals. This allows for the glass discharge tube to be removed in the event it is damaged or for experimentation.

CO2 Laser Theory and Mechanics

A CO2 laser is comprised of an optical cavity, a gain medium, and a pumping source. The optical cavity is designed to be a resonant chamber. To achieve resonance, the length of the optical cavity must be an integer multiple of half the wavelength to be output. For a CO2 laser, the theoretical half wavelength is 5.3 micrometers so the only considerations for the length of the tube are power density and ensuring the plasma discharge can overcome the resistance of a longer tube. The optical cavity is designed with an output coupler at one end. The output coupler is a partial mirror that will reflect a portion of the output beam back through the cavity while also allowing some of the beam to escape as the laser output. The gain medium is the material used to fill the inside of the optical cavity. The gain medium allows the laser to achieve optical gain. The optical cavity for a CO2 laser is filled with a gas mixture of CO2, nitrogen and helium. Finally, the laser is pumped with a source of external energy that will excite the atoms of the gain medium. Various sources of energy can be used to pump a laser such as light energy, electrical energy, and thermal energy. This CO2 laser will use a high voltage power supply to pump the laser.

One characteristic of laser operation that differs from conventional lighting sources is the ratio of atoms in their ground state energy levels to energetically excited atoms. For a controlled volume of gas atoms not being pumped with an external energy source the population of atoms at the ground energy level far exceeds the population of atoms at higher energy levels (of which there are none). In the case of a neon light, the gas atoms are energized with an electric discharge. Many of the atoms become excited and move to higher energy levels. The excited atoms will spontaneously move back to their ground state energy level and release their excess energy in the form of photons. However, the population of ground state atoms must exceed the population of excited atoms or the process would not sustain because there would be too many excited atoms not transitioning to lower energy levels and releasing photons. In contrast, a laser must be able to maintain a population of excited atoms that exceeds the population of ground state atoms to achieve optical gain. A population of excited atoms that exceeds the population of ground state atoms is called a population inversion.

A laser can achieve optical gain when a population inversion is reached because of a quantum phenomenon called stimulated emission. In the case of a neon light, excited atoms can spontaneously emit photons. In the case of a laser, the excited atoms in the gain medium are stimulated to release more photons through incidence with reflected photons that were initially spontaneously emitted. Coincidentally, stimulated emission results in emitted photons that have identical wavelength and phase to the incident photons. Since the optical cavity is fit with a mirror at one end and a partial mirror at the other end, photons can reflect back thousands of times stimulating more photon emissions with each pass. The need for a population inversion is now apparent; when photons are initially emitted, the atoms from which they were emitted from return to their ground state. If a population inversion was not maintained, there would remain few excited atoms left for the initial photons to stimulate when they returned, and no gain would be achieved. If enough photons are emitted to overcome possible losses such as not enough of a population inversion, an output coupler that does not have a proper reflectivity, and other inefficiencies related to fabricating the laser, optical gain will be achieved, and the laser will emit a beam.

Constructing the Full Laser

Laser Tube Assembly

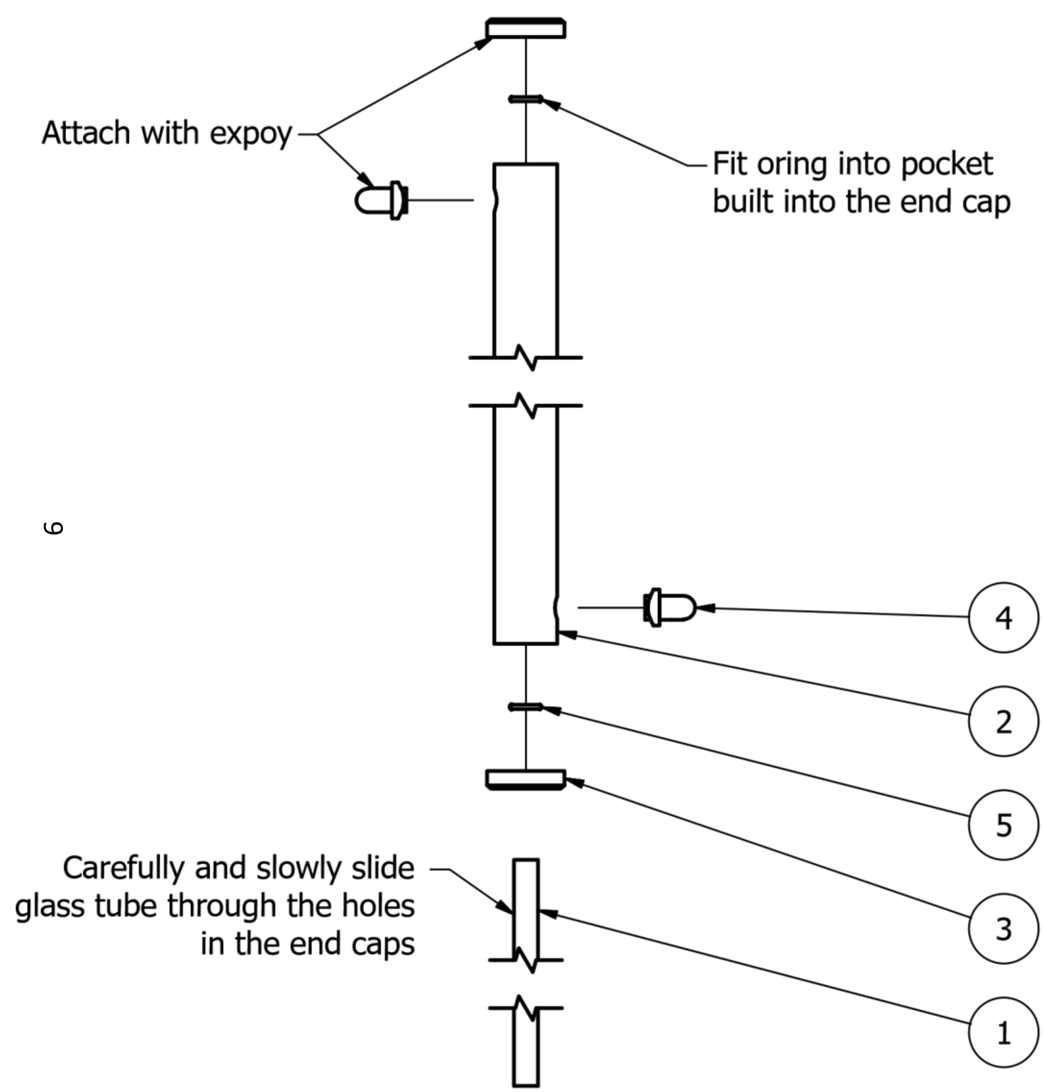
The laser tube assembly is constructed from two unique subassemblies: the discharge tube assembly and the optics mount and electrode assembly.

Discharge Tube Assembly

The discharge tube assembly will contain the plasma discharge that will occur during operation of the laser. The discharge tube will also have water cooling jacket to cool the laser to a more efficient operating temperature. The discharge tube will be constructed from a glass tube, a plastic cooling jacket, two 3D printed end caps, and two 3D printed water inlet/outlet ports.

Each end cap is designed with a pocket to house an oring. The oring will create a water tight seal between the glass discharge tube and each end cap. The glass tube will be installed by carefully sliding the glass discharge tube through the holes on each end cap.

FRONT
SCALE .25



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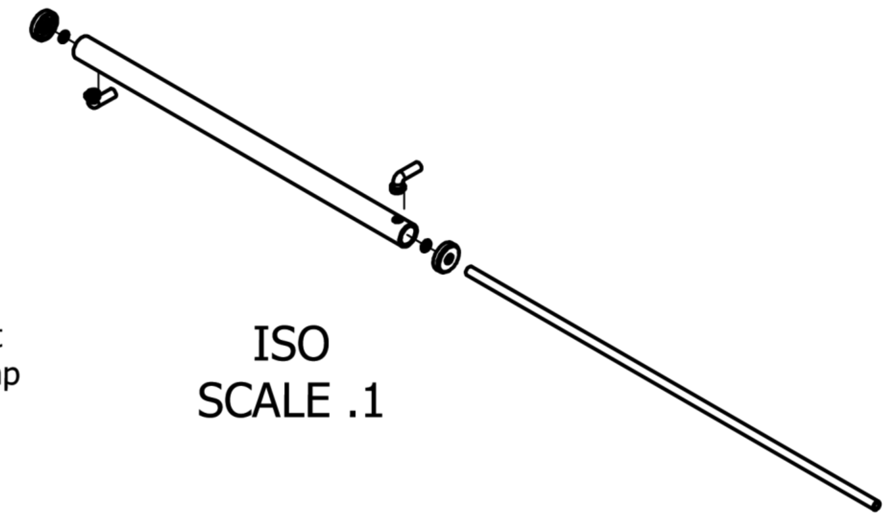

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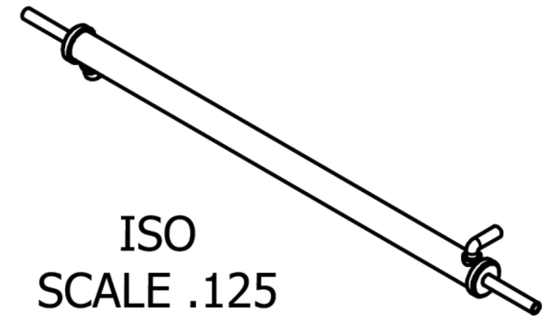
1	1	Glass_Discharge_Tube	Glass
2	1	Cooling_Jacket	PVC-Piping
3	2	Cooling_End_Cap	ABS Plastic
4	2	Cooling_Inlet_Oulet	ABS Plastic
5	2	Oring_Large	Rubber, Silicone

DATE: 10/24/18	PROJECT: CO2 LASER Mk. 3
DESIGNER: Jacob	
PART NAME: Discharge Tube Assembly Drawing - Exploded	



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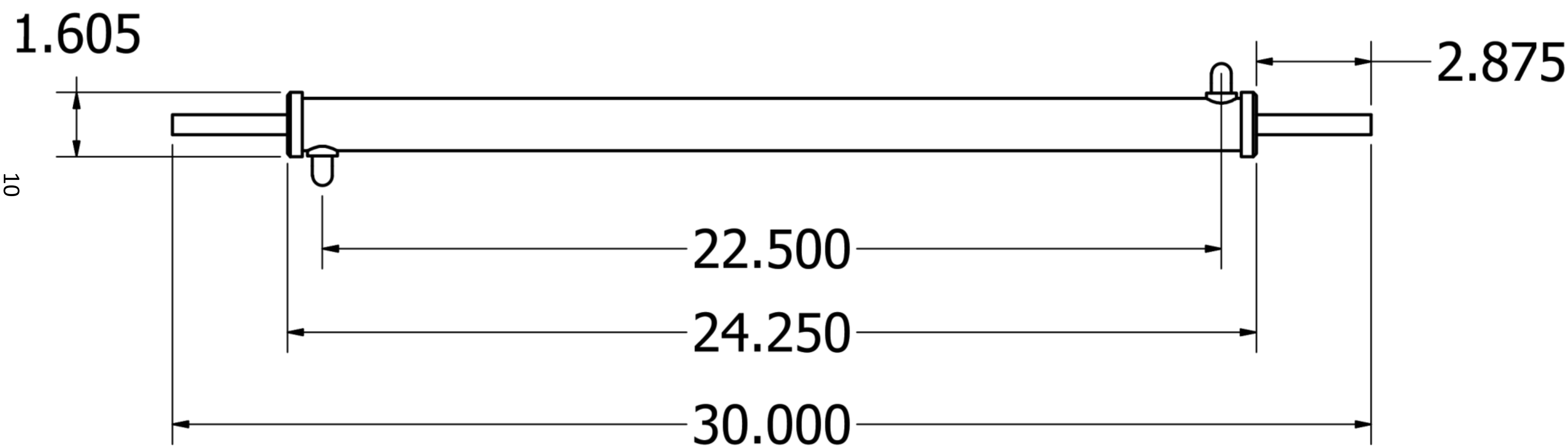


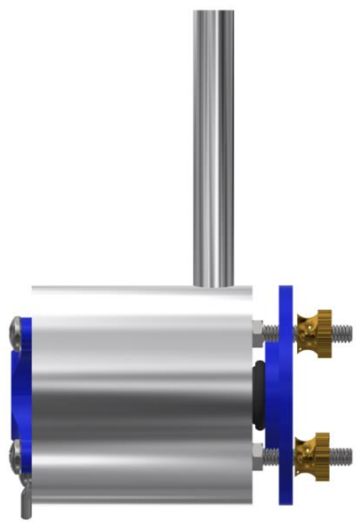
FRONT
SCALE .25

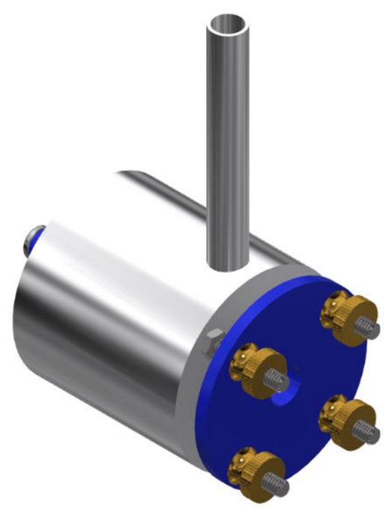
DATE: 10/24/18	PROJECT: CO2 LASER Mk. 3
DESIGNER: Jacob	
PART NAME: Discharge Tube Assembly Drawing - Dimensional	

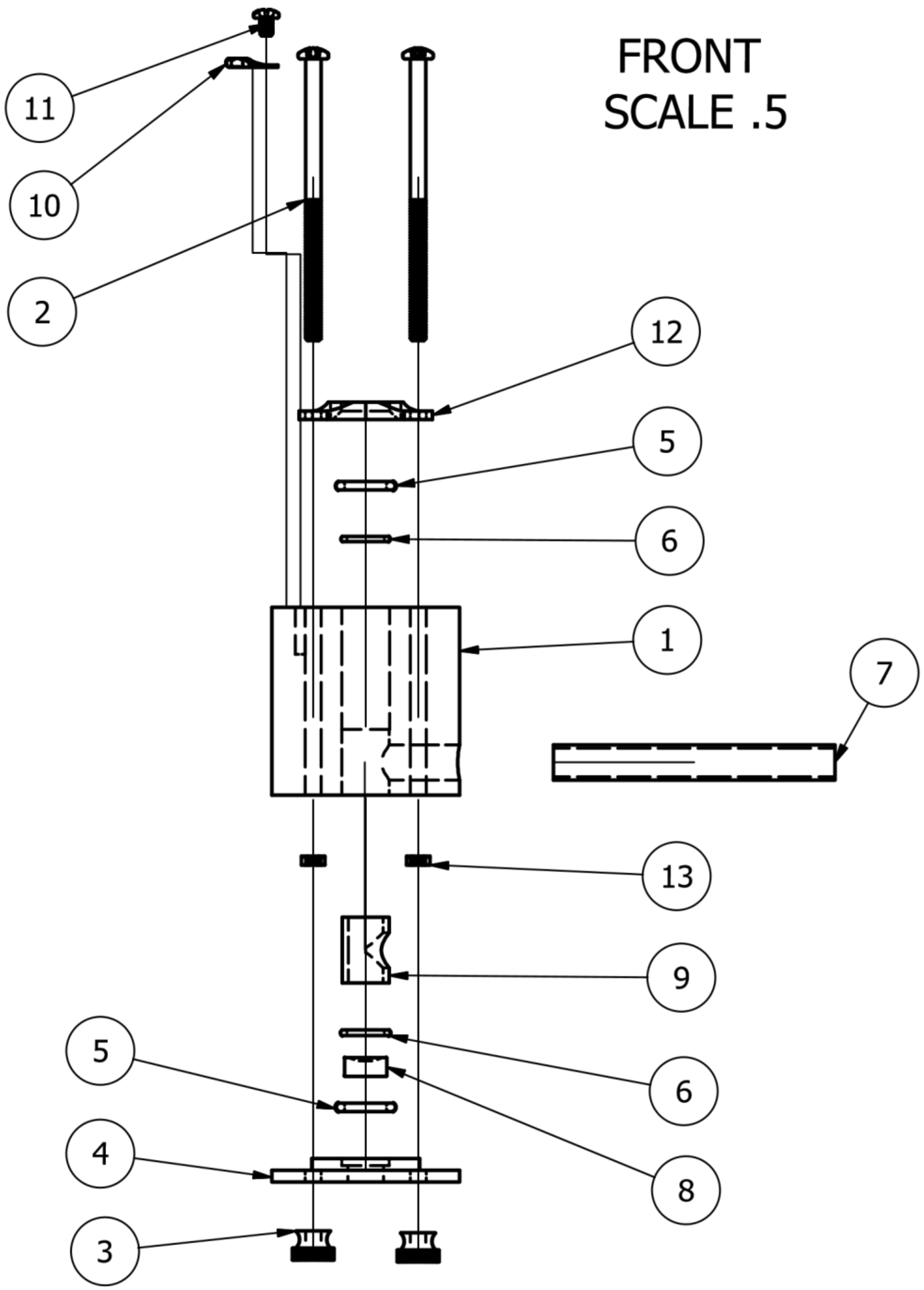
Optics Mount and Electrode Assembly

The optics mount and electrode assembly will house and align the output coupler and surface mirror at either end of the discharge tube. The optics mount will also serve to house the electrode assembly and will be connected to the power supply.

Two of these mounts will be constructed. The main body of the mount will be fabricated from 6061 alumium. The mount will have a center hole to accodmodate the end of the glass discharge tube and stainless steel electrode. Additonally, four screws will run through the mount and connect to the optics adjustment plate to allow for fine control of the mirror sandwiched between the mount and the plate. A small hole drilled into the front botton of the mount will accodmate a small screw and ring attachment that will connect the power supply to the mount. On the front of the mount, an oring and oring clamp will be used to create a seal between the glass discharge tube and the mount during assembly.







PARTS LIST			
ITEM	QTY	PART NUMBER	MATERIAL
1	1	Optics_Mount	Aluminum 6061
2	4	Optics_Adj_Screw	Stainless Steel
3	4	Knurled_Thumb_Nut	Brass
4	1	Optics_Adjustment_Plate	ABS Plastic
5	2	Oring_Large	Rubber, Silicone
6	2	Oring_Small	Rubber, Silicone
7	1	Gas_Inlet_Outlet	Aluminum 6061
8	1	HR_Mirror	Silver
9	1	Electrode	Stainless Steel
10	1	Ring_Terminal_Electrical	Steel, Cast
11	1	Electrical_Attachement_Screw	Stainless Steel
12	1	Front_Oring_Clamp	ABS Plastic
13	4	Narrow_Hex_Nut	Stainless Steel

DATE:
10/24/18

DESIGNER:
Jacob

PART NAME:
Optics Mount and Electrode Assembly - Exploded

PROJECT: CO2 LASER Mk. 3

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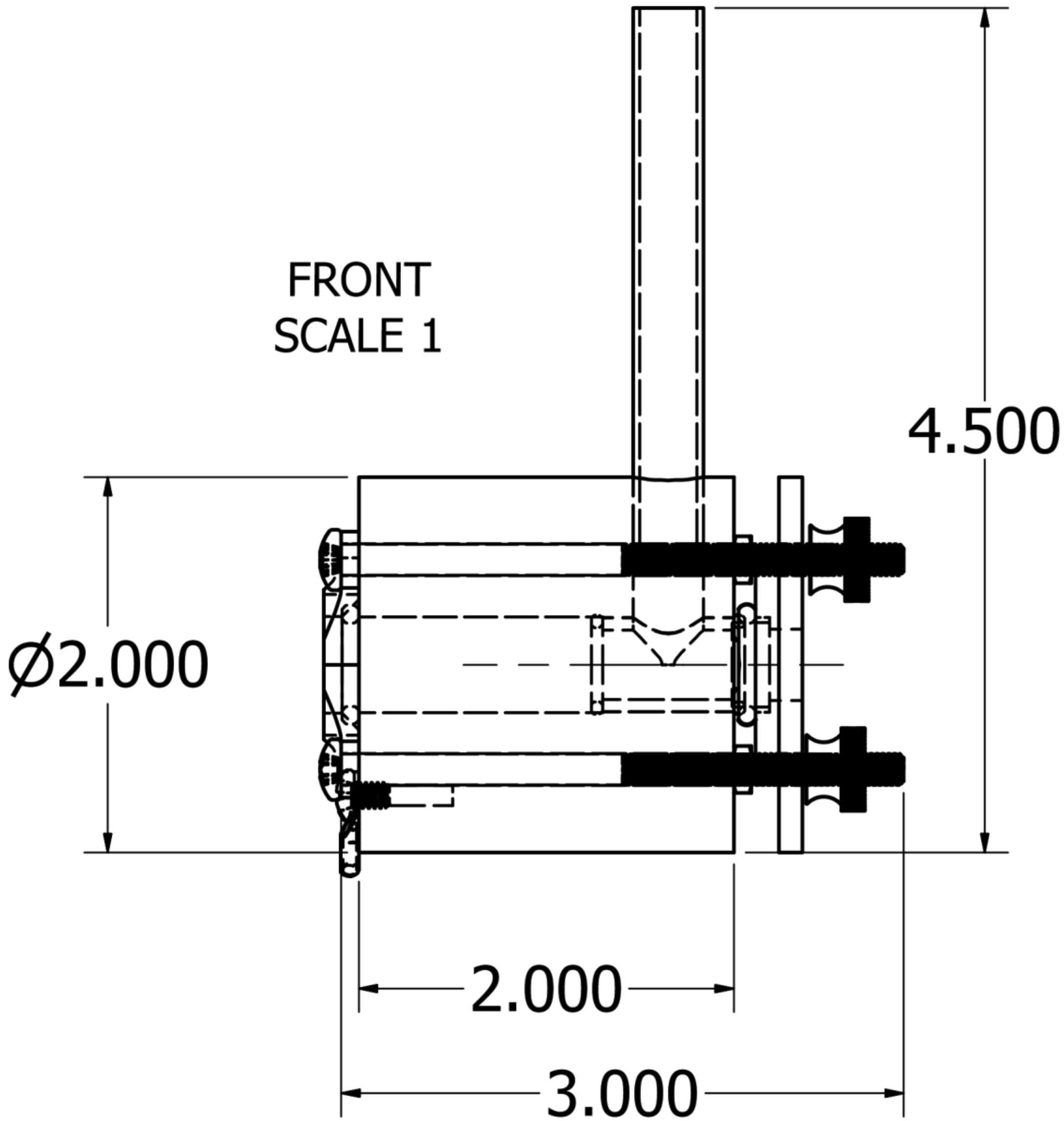

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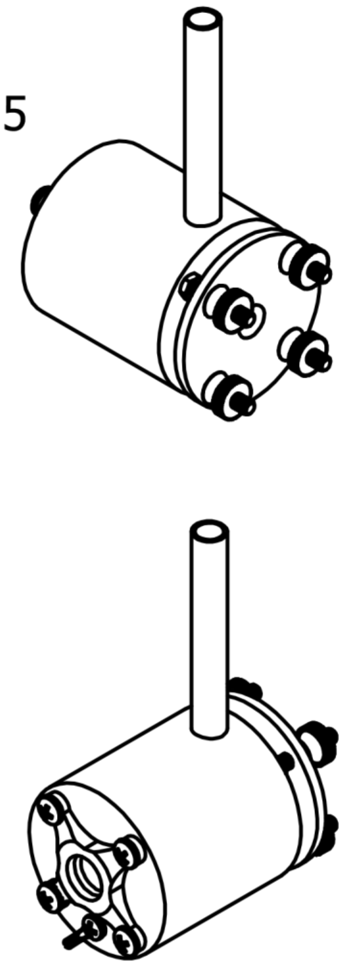
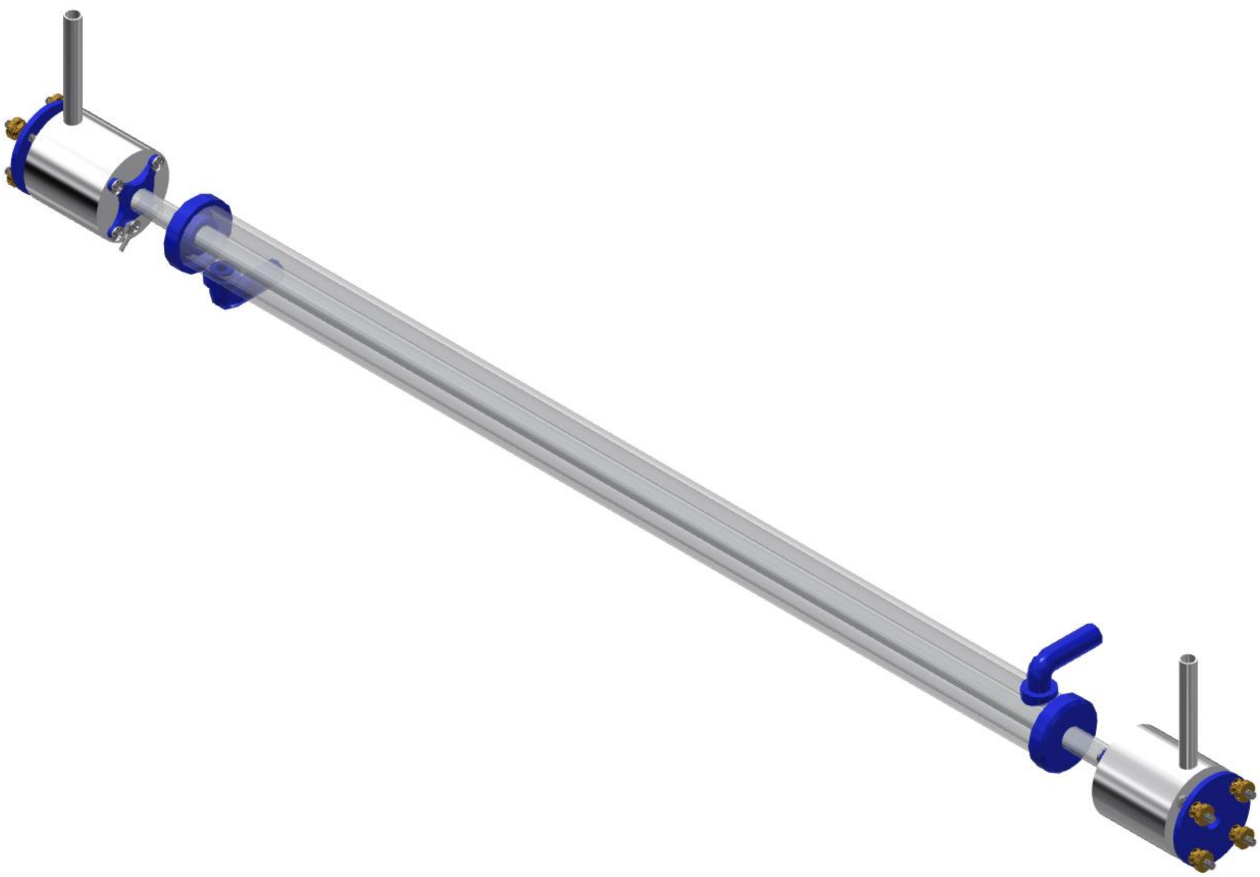


DATE: 10/24/18	PROJECT: CO2 LASER Mk. 3
DESIGNER: Jacob	
PART NAME: Optics Mount and Electrode Assembly - Dimensional	

Laser Tube Assembly

Once the discharge tube and two optics mount and electrode assemblies have been constructed, the laser tube can be constructed. The assembly of the laser tube is designed to be assembled without any permanent methods of attachment (i.e. glues and sealants). This allows the laser tube to be dissembled for repair or experimentation of tube length.

The optics mount and electrode assemblies will be connected to the discharge tube with an oring and an oring clamp on each mount. The oring clamp and oring will maintain an airtight seal between the end of the glass discharge tube and the optics mount and electrode assembly.



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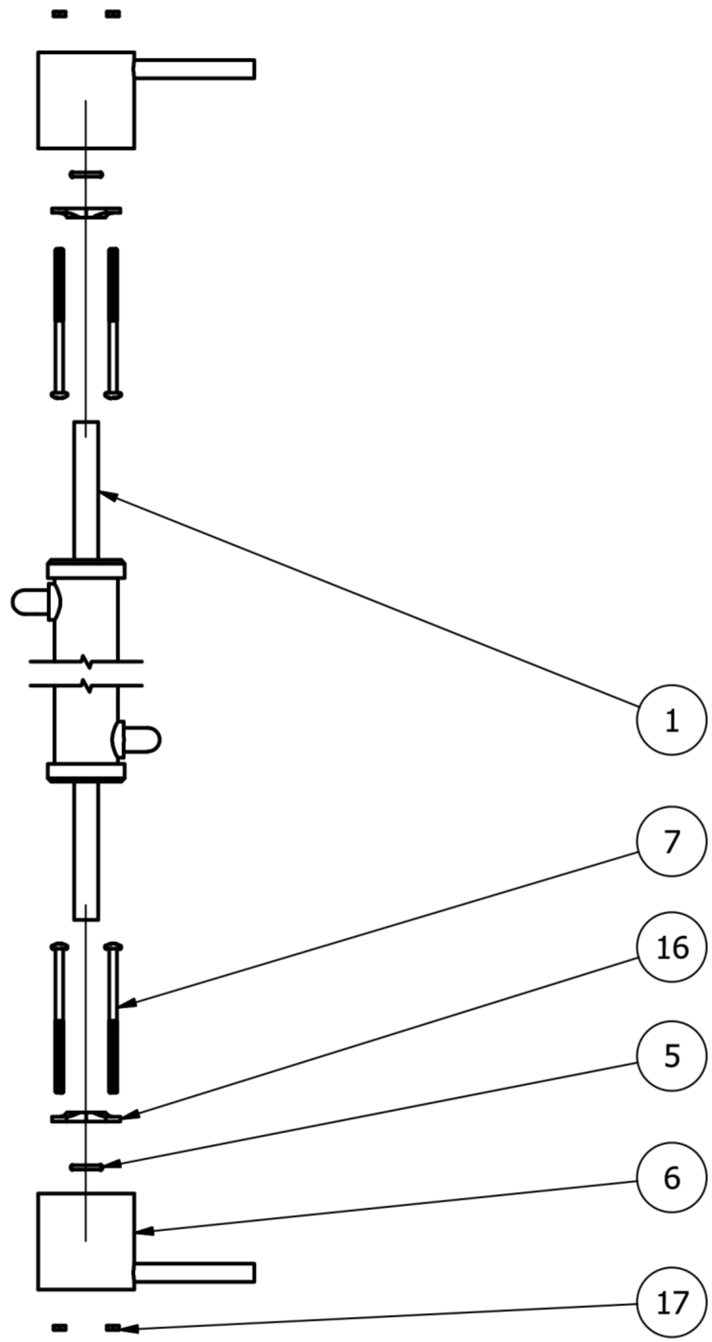

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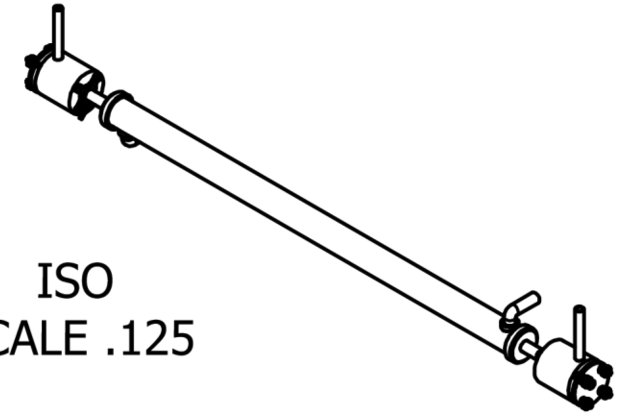


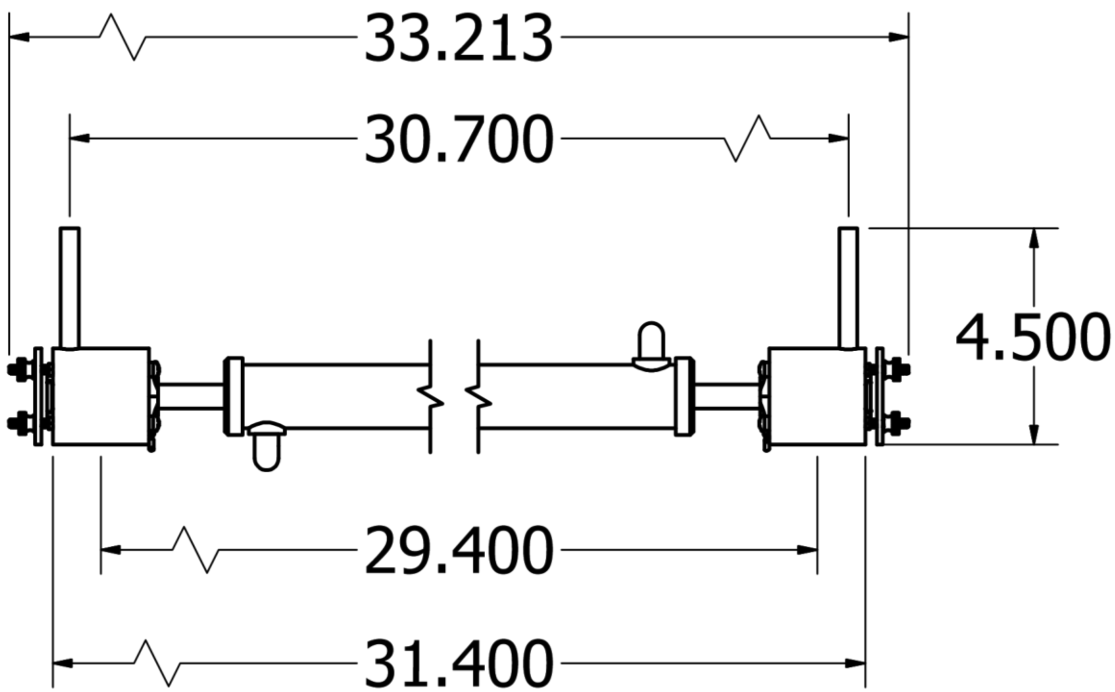
PARTS LIST			
ITEM	QTY	PART NUMBER	MATERIAL
1	1	Glass_Discharge_Tube	Glass
5	6	Oring_Large	Rubber, Silicone
6	2	Optics_Mount	Aluminum 6061
7	8	Optics_Adj_Screw	Stainless Steel
16	2	Front_Oring_Clamp	ABS Plastic
17	8	Narrow_Hex_Nut	Stainless Steel

DATE:
10/24/18

DESIGNER:
Jacob

PART NAME:
Laser Tube Assembly
-Exploded

**PROJECT:
CO_2 LASER
Mk. 3**



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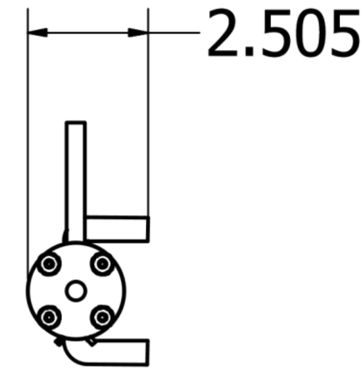

SIDE
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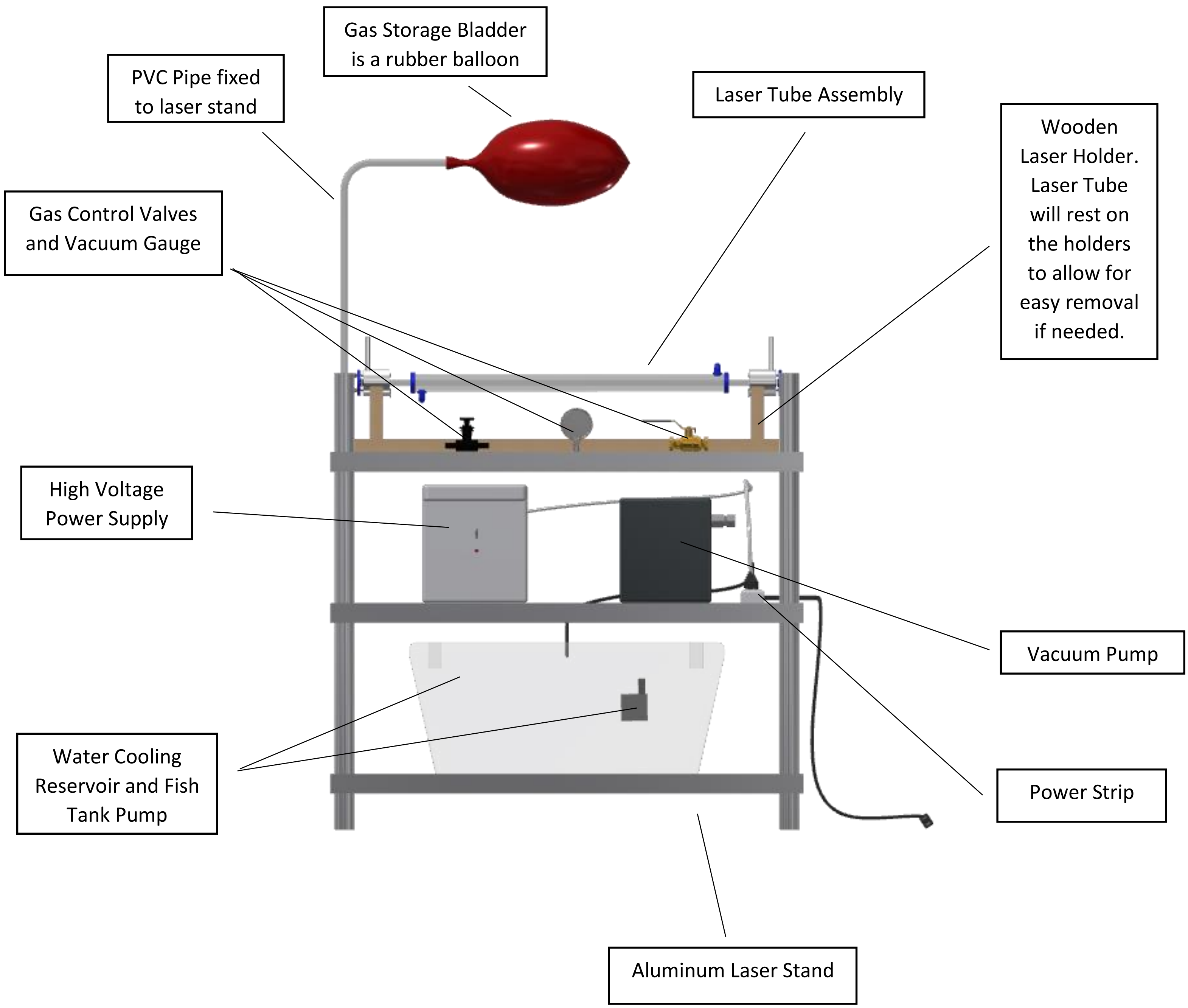
DATE: 10/24/18	PROJECT: CO2 LASER Mk. 3
DESIGNER: Jacob	
PART NAME: Laser Tube Assembly - Dimensional	

Constructing the Entire Laser Assembly

Placing Components on Laser Stand

The components to be placed on the laser stand are the laser tube assembly, wooden laser holder, vacuum pump, gas storage bladder, vacuum and gas control valves, vacuum gauge, power supply, power strip, and water-cooling reservoir.

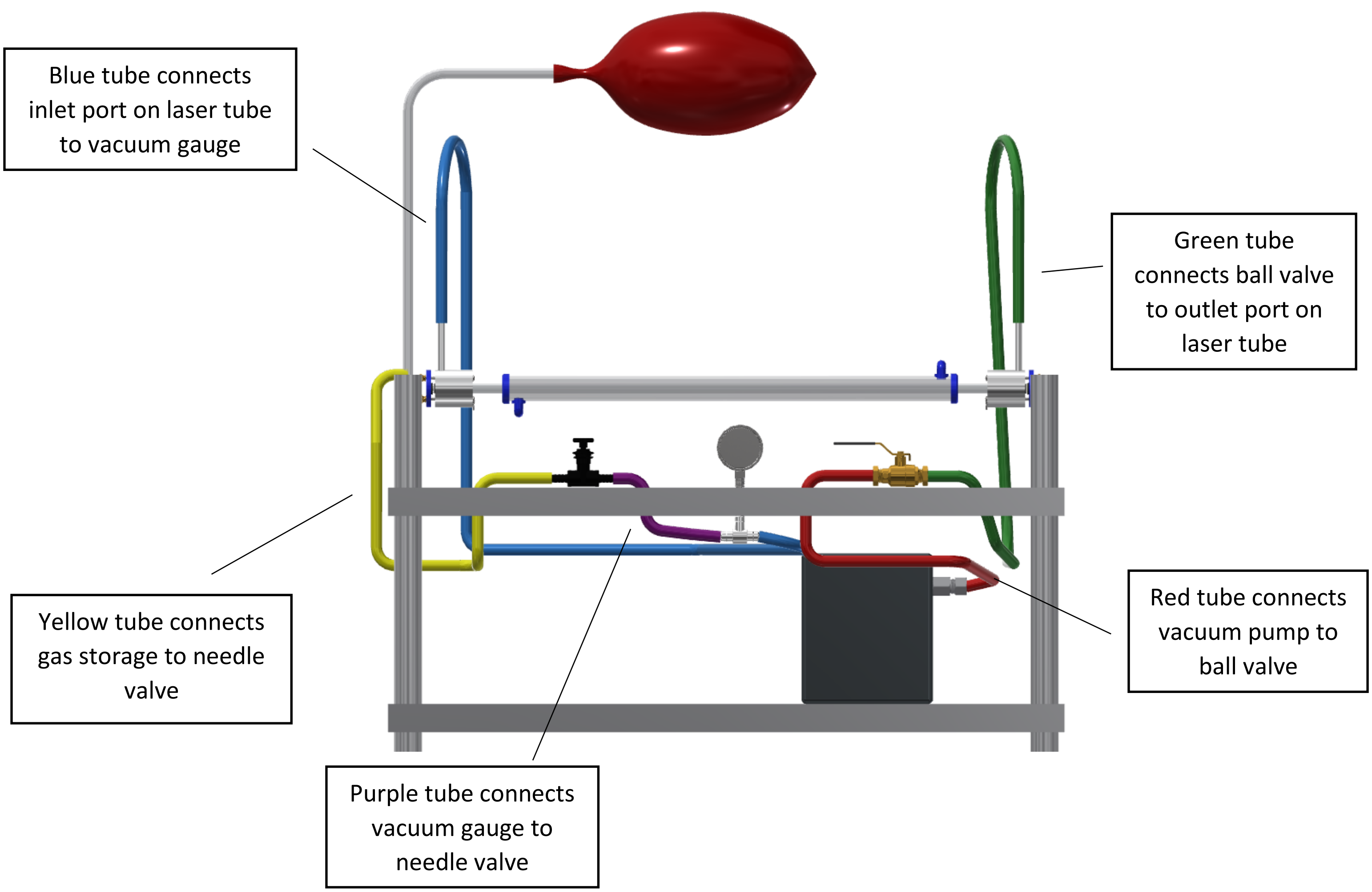


Constructing the Laser Holders

Specifications for constructing the wooden laser holder will not be provided. However, the laser holder must satisfy two requirements: (1) the laser tube assembly must be secure when resting on the laser holder but must be easily removable; (2) the laser holder will hold the laser tube in a fashion such that no torque is applied to the glass tube when the plastic gas lines are connected to the inlet/outlet ports on the optics mounts. If the second requirement is not satisfied, the gas lines will pull on the optics mounts and apply stress on the glass tube.

Connecting the Gas Tubing

Five sections of braided vinyl tubing will be used to connect the vacuum pump and gas supply to the laser tube. It is extremely important to ensure the tubing section that connects the laser tube to the ball valve (color: green) and the tubing section that connects the laser tube to the vacuum gauge (color: blue) are longer than the length of the discharge tube. Since the green and blue tubing sections will be at the same low pressure as the discharge tube, there is a chance they could essentially become high voltage wires. If they are longer than the discharge tube, charge will travel through the discharge tube and not the gas lines.



Connecting the Water-Cooling System

A fish tank pump will be used to pump the water from the water-cooling reservoir up through vinyl tubing to the water-cooling jacket. The water-cooling jacket is designed with two inlet/outlet ports for water to enter and exit. One port is on the top and other is on the bottom. The vinyl tube connected directly to the fish tank pump must be connected to the inlet port on the bottom of the water-cooling jacket. This ensures the cooling jacket fills with water before it begins to drain back into reservoir.

Grounding the Power Supply and Laser Stand

To properly ground the power supply, a three-pronged connector will be attached to the primary lines and ground on the power supply. From a sanded area on the steel laser stand, a wire will connect the entire laser stand to a ground prong on the power strip. The power strip will be plugged into a 3-pronged wall outlet that is connected directly to earth ground.

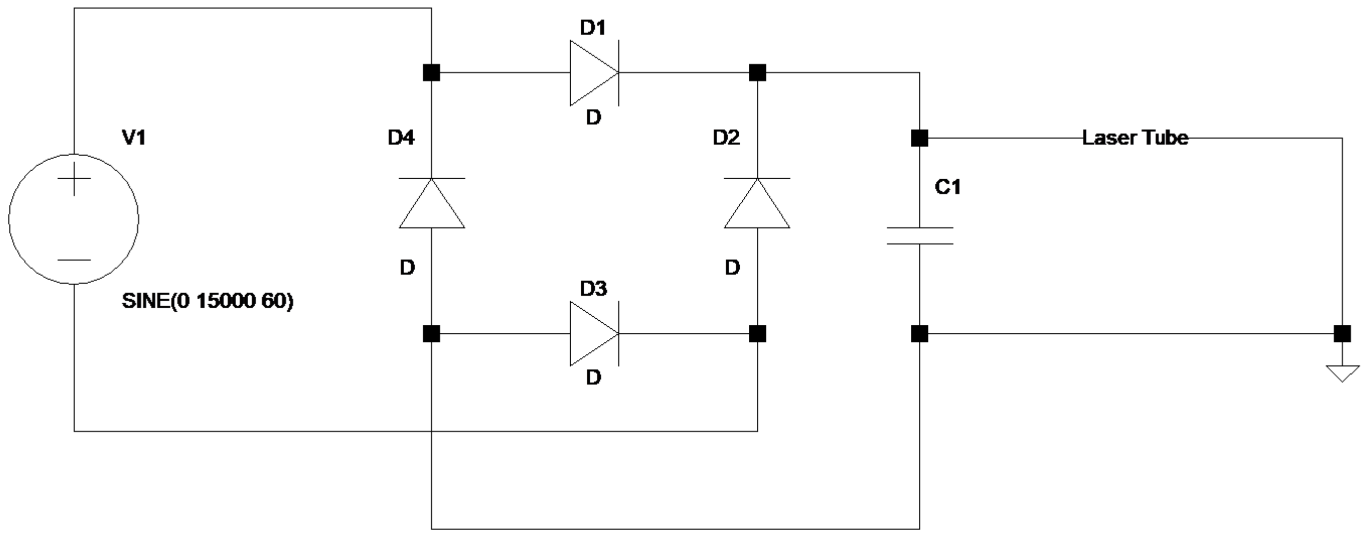
In the event of a short circuit of the high voltage power supply itself or from another part touching the laser stand, the short will be directed through the metal laser stand, into the ground of the power strip, and into earth ground. Because there are so many ways for the laser to become electrically conductive in places it should not be, the proper grounding of this laser is EXTREMELEY IMPORTANT!

Preparing the High Voltage Power Supply

The laser will be powered by a neon sign transformer that outputs 15,000 Volts AC at 30 milliamps and 60 Hertz. Although the laser can run when pumped with an AC waveform, maximum efficiency is only achieved when the laser is pumped with DC current. A bridge rectifier will be constructed from high voltage diodes.

Converting AC to DC Output

To convert the AC output of the neon sign transformer into DC current, a bridge rectifier circuit will be assembled. The bridge rectifier will convert the AC output into a full wave pulsed DC signal at 120 Hertz. A filter capacitor will be connected in parallel to the laser tube to smooth the pulsed DC signal.

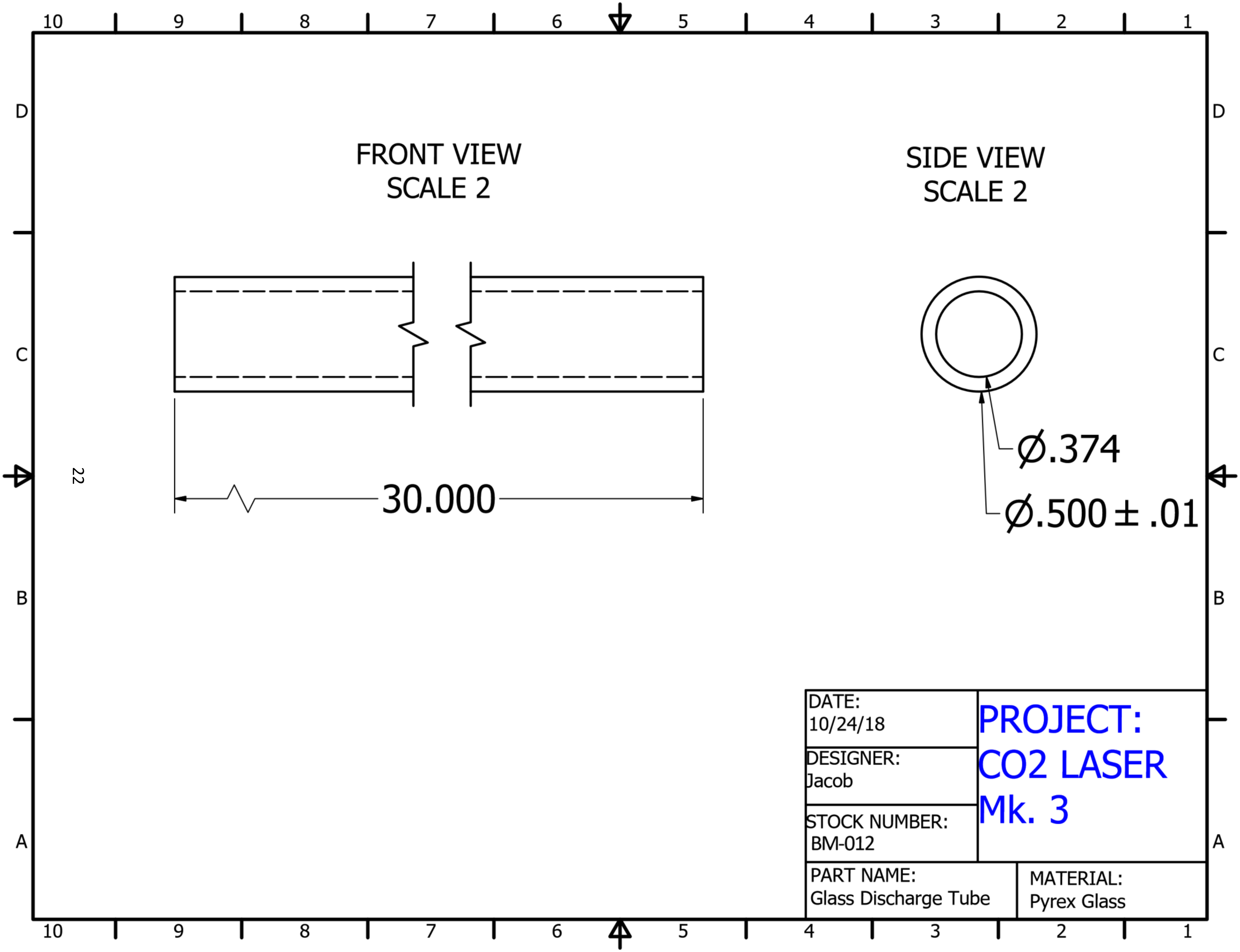


Ref.	Part Name	Qty.
V1	Neon Sign Transformer	1
D1-D4	Diode - 15kV, 30mA	4

Parts Reference

Bill of Materials

	Item	Part Name	QTY	Material	Stock Number	Acquired From
Discharge Tube Assembly	1	Glass_Discharge_Tube	1	Borosillicate Glass	BM-012	Wale Apparatus
	2	Cooling_Jacket	1	Clear PVC Piping	49035K45	McMaster Carr
	3	Cooling_End_Cap	2	ABS Plastic		3D Printed
	4	Cooling_Inlet_Oulet	2	ABS Plastic		3D Printed
Optics Mount and Electrode Assembly	5	Optics_Mount	1	Aluminum 6061	8974K71	McMaster Carr
	6	Electrode	1	316 Stainless Steel	89495K425	McMaster Carr
	7	Gas_Inlet_Outlet	1	Aluminum 6061	89965K491	McMaster Carr
	8	Optics_Adj_Screw	8	18-8 Stainless Steel	91772A209	McMaster Carr
	9	Knurled_Thumb_Nut	8	Brass	92741A120	McMaster Carr
	10	Electrical_Attachement_Screw	2	316 Stainless Steel	91735A142	McMaster Carr
	11	Narrow_Hex_Nut	8	18-8 Stainless Steel	90730A009	McMaster Carr
	12	Oring_Large	6	Rubber, Silicone	1283N54	McMaster Carr
	13	Oring_Small_Square	4	Rubber, Silicone	1182N012	McMaster Carr
	14	HR_Mirror	1	Silver Coated Silicone Substrate		Laser Research Optics
	15	Output_Coupler	1	Zinc Selenide		Laser Research Optics
	16	Optics_Adjustment_Plate	2	ABS Plastic		3D Printed
Gas Supply and Vacuum System	17	Vacuum Gauge	1		3941K53	McMaster Carr
	18	Tee Barb Tube Fitting	1		5058K58	McMaster Carr
	19	Female Threaded Barb Tube Fitting	2		5058K68	McMaster Carr
	20	Needle Valve	1		7781K33	McMaster Carr
	21	Brass Barb Ball Valve	1			F.W. Webb Plumbing
	22	PVC_Gas	1	PVC Piping		Home Depot
	23	Braided Vinyl Tubing	25 ft	Vinyl	204667	Home Depot
	24	Vacuum_Pump	1		61176	Harbor Freight
	25	Balloon	1	Rubber		Amazon
Power Supply	26	Ring Terminals	2	Steel	69405K5	McMaster Carr
	27	20 kV Insulated Wire	8 ft		WIRE20KV	Information Unlimited
	28	High Voltage Diode	4		VG20KV200s	Information Unlimited
	29	Neon_Power_Supply	1			Ebay
General Assembly and Water Cooling System	30	Laser_Tube_Holders	1	Wood Board		Home Depot
	31	Laser_Stand	1	Steel		Container Store
	32	Power_Strip	1			Amazon
	33	Ring Clamps		Steel		Home Depot
	34	Water_Tank	1			Amazon
	35	Fish_Tank_Pump	1			Amazon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SIDE VIEW
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∅.500 ± .01
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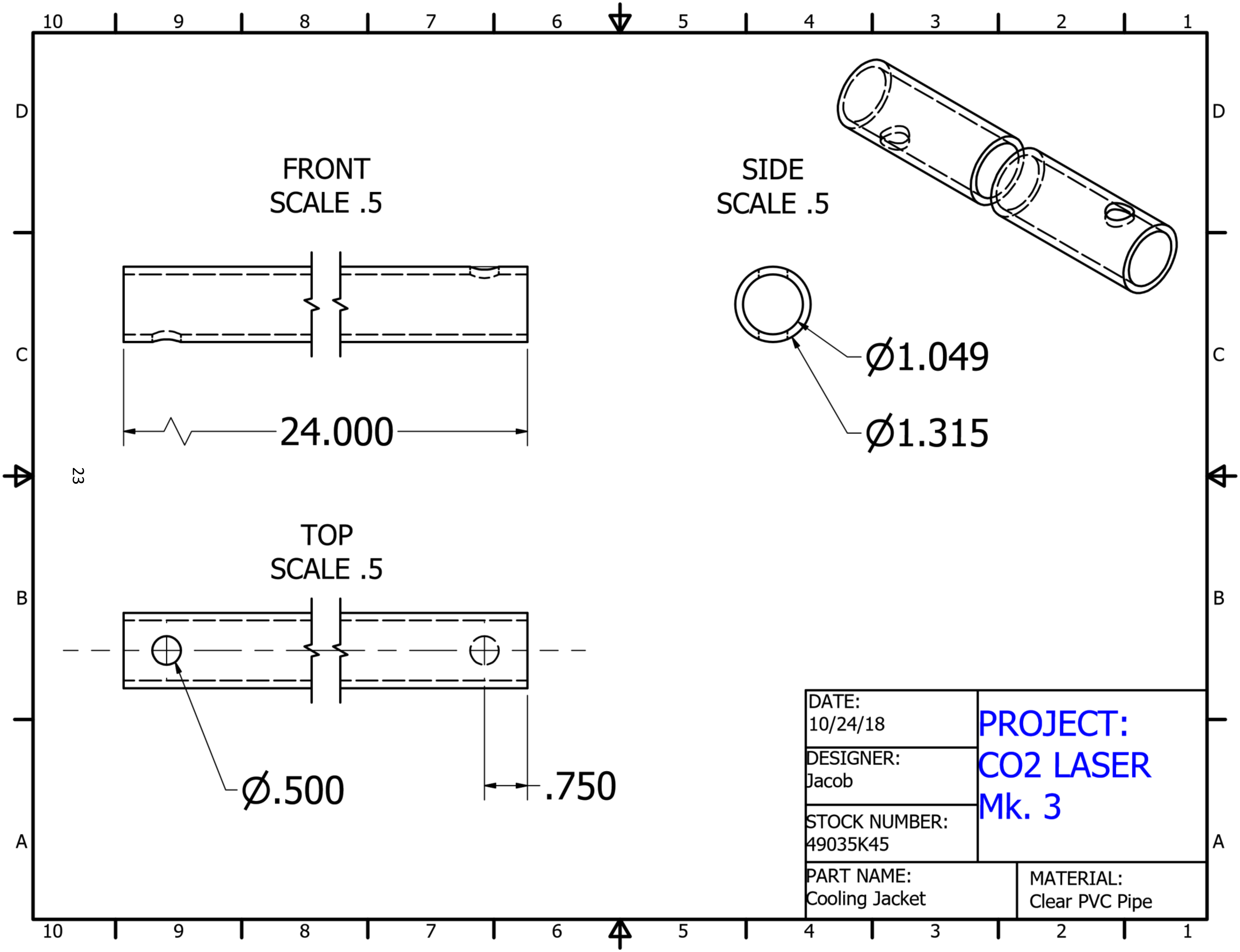
10/24/18
DESIGNER:
Jacob
STOCK NUMBER:
BM-012
PROJECT:
CO2 LASER
Mk. 3
PART NAME:
Glass Discharge Tube
MATERIAL:
Pyrex Glass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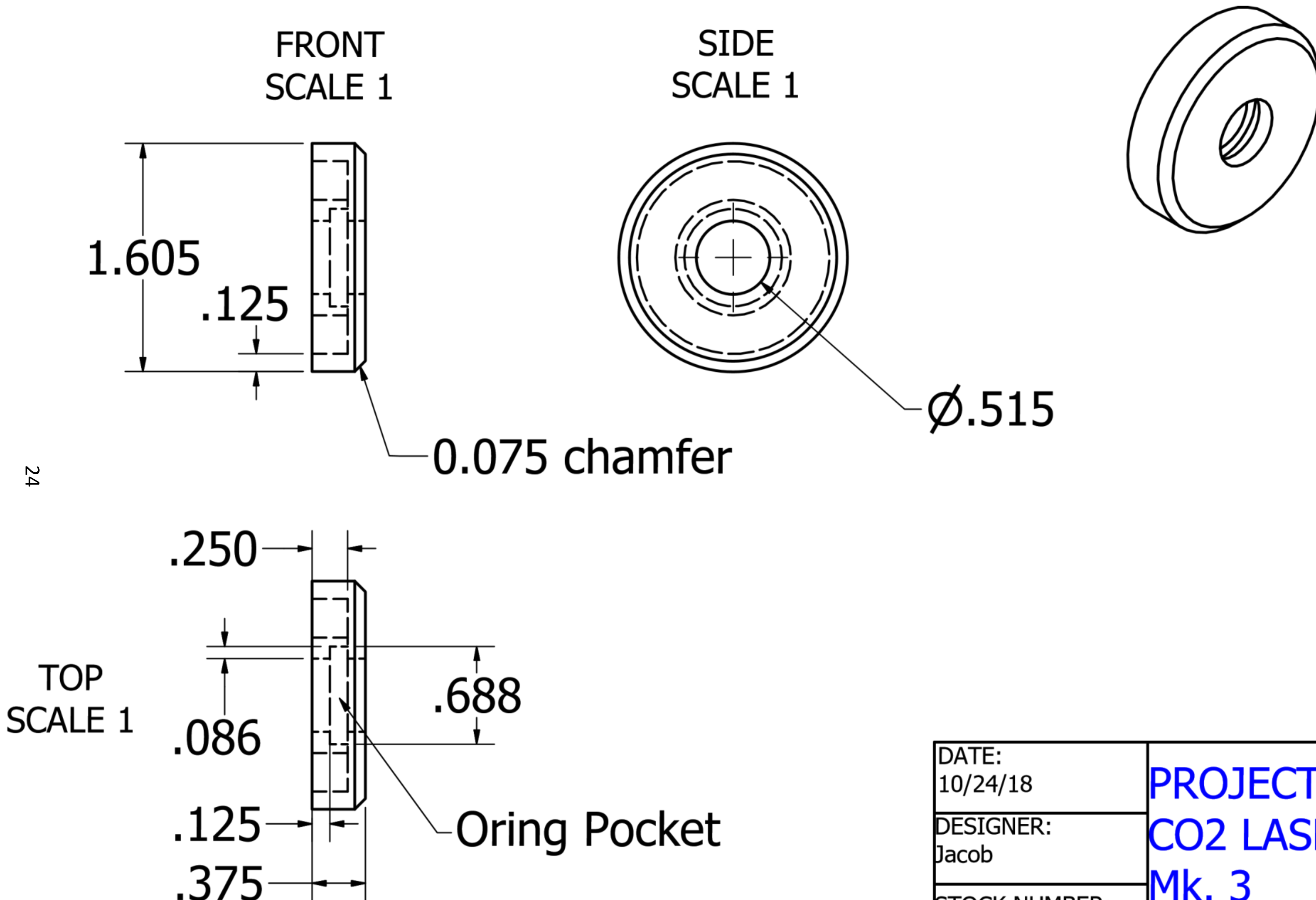
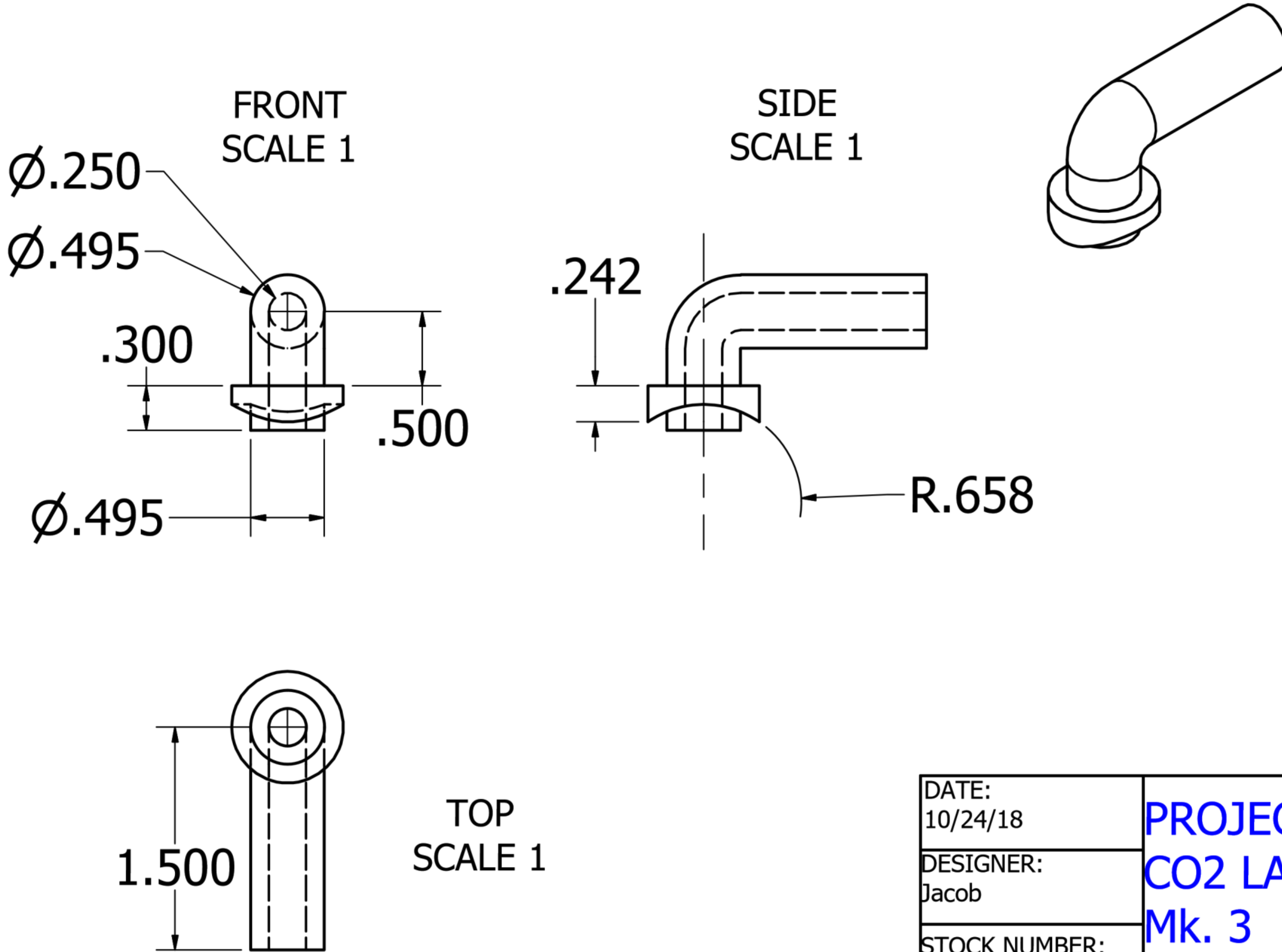
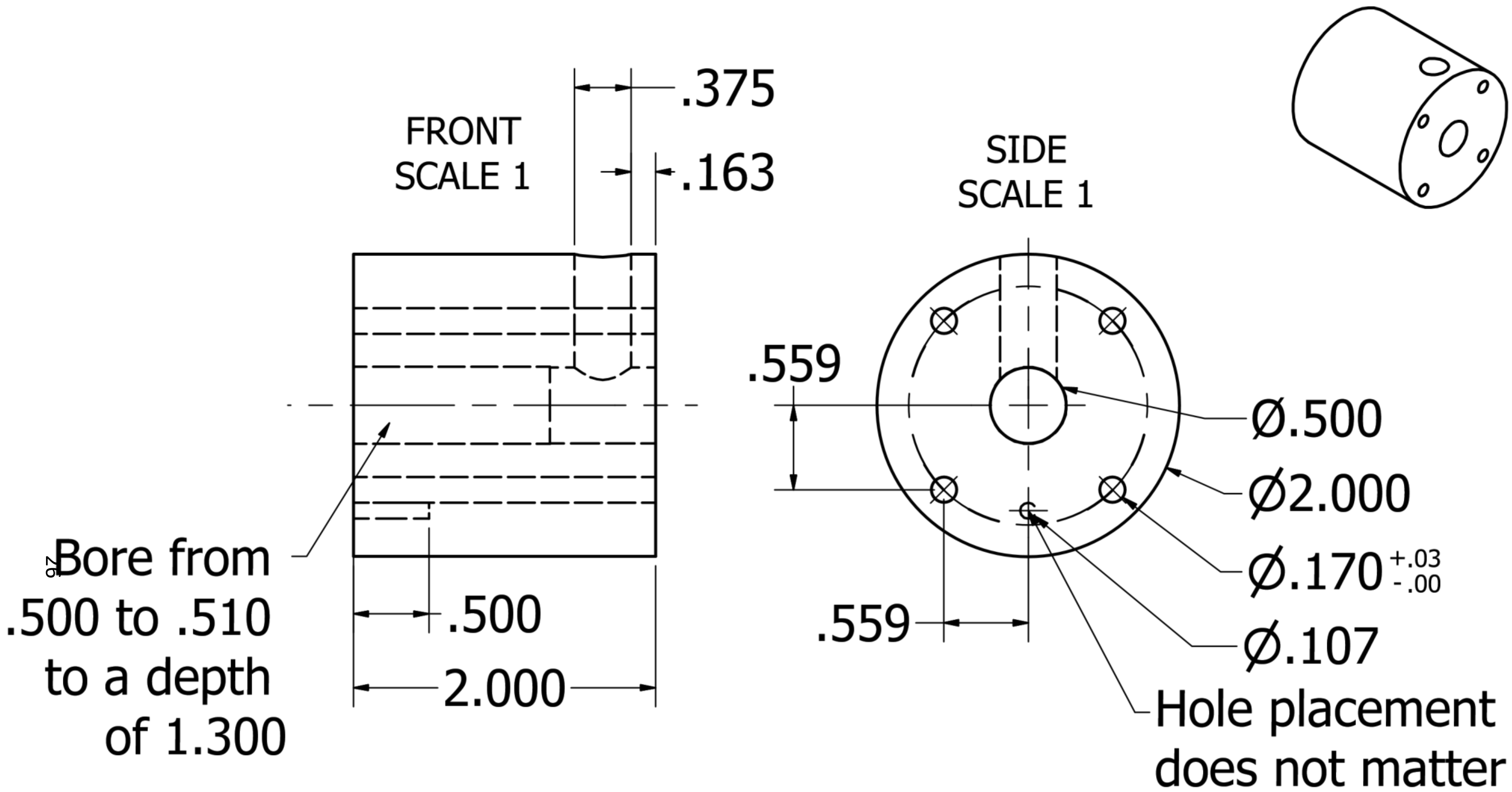
10/24/18
DESIGNER:
Jacob
STOCK NUMBER:
49035K45
PART NAME:
Cooling Jacket
MATERIAL:
Clear PVC Pipe
PROJECT:
CO2 LASER
Mk. 3



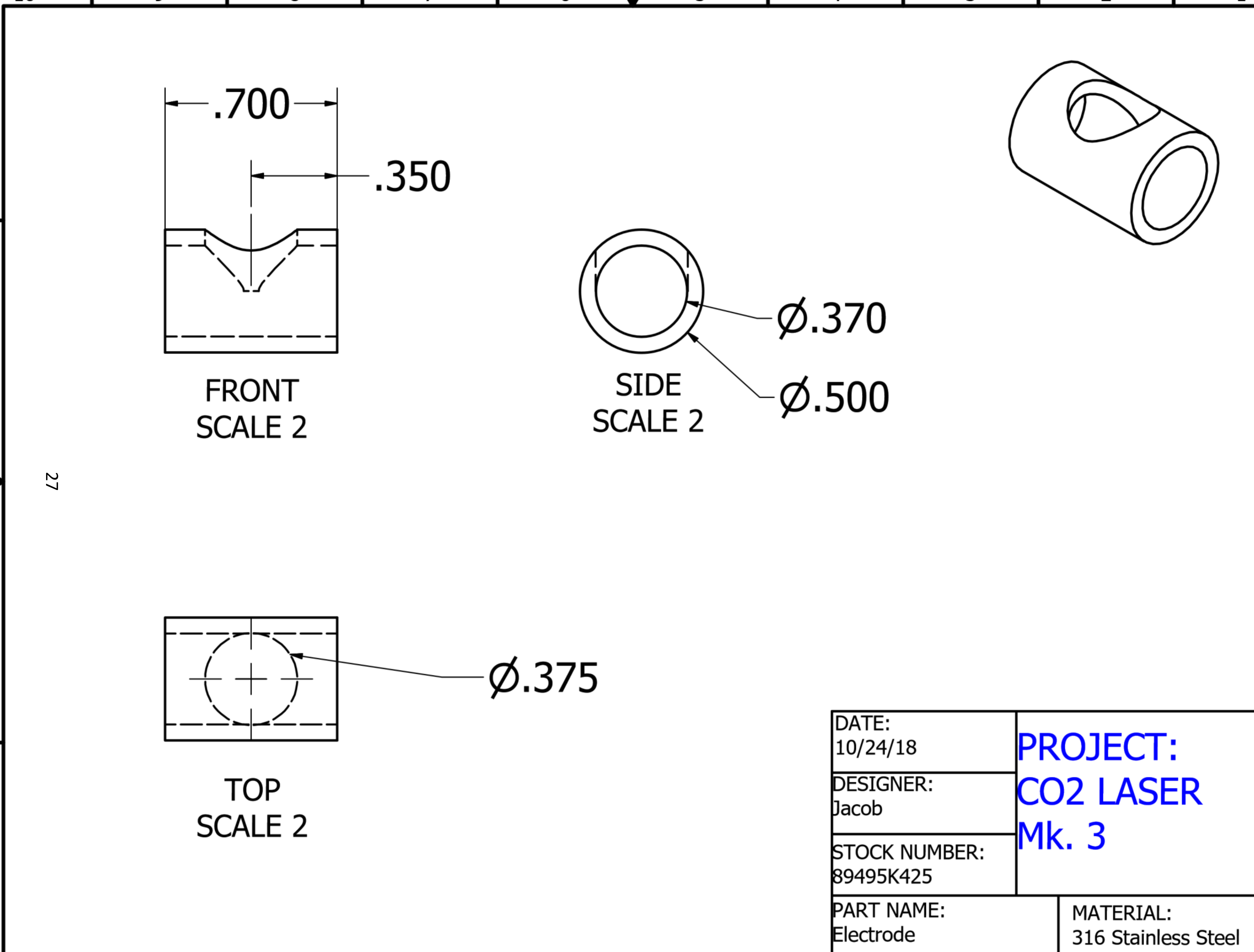
DATE: 10/24/18	PROJECT: CO2 LASER Mk. 3
DESIGNER: Jacob	
STOCK NUMBER:	
PART NAME: Cooling End Cap	MATERIAL: ABS Plastic



DATE: 10/24/18	PROJECT: CO2 LASER Mk. 3
DESIGNER: Jacob	
STOCK NUMBER:	
PART NAME: Cooling Inlet/Outlet	MATERIAL: ABS Plastic



DATE: 10/24/18	PROJECT: CO2 LASER Mk. 3
DESIGNER: Jacob	
STOCK NUMBER: 8974K71	
PART NAME: Optics Mount	MATERIAL: 6061 Aluminum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10/24/18
DESIGNER:
Jacob
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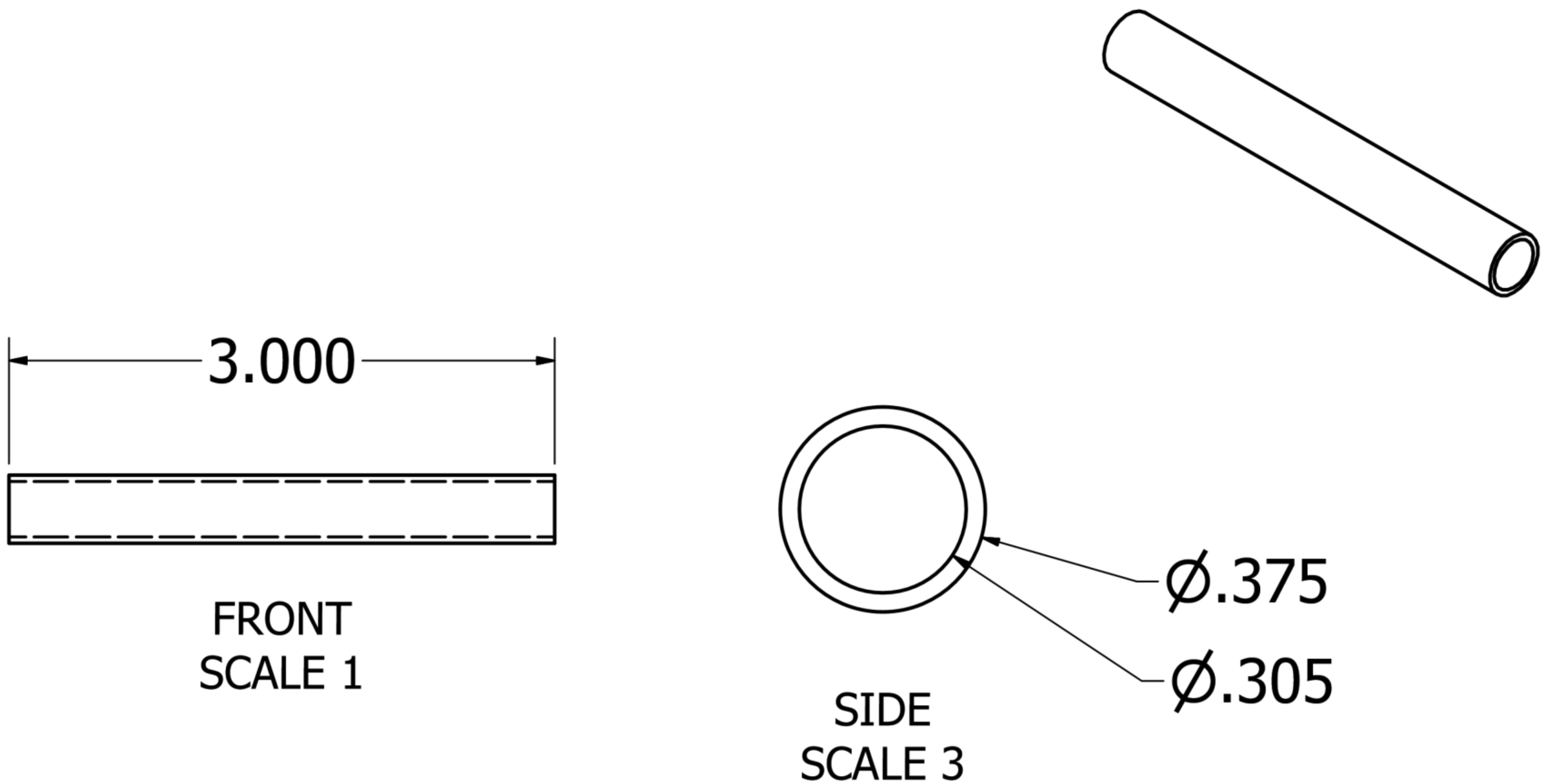
89495K425
PART NAME:
Electrode
PROJECT:
CO2 LASER
Mk. 3
MATERIAL:
316 Stainless Steel



DATE: 10/24/18	PROJECT: CO2 LASER Mk. 3
DESIGNER: Jacob	
STOCK NUMBER: 89965K491	
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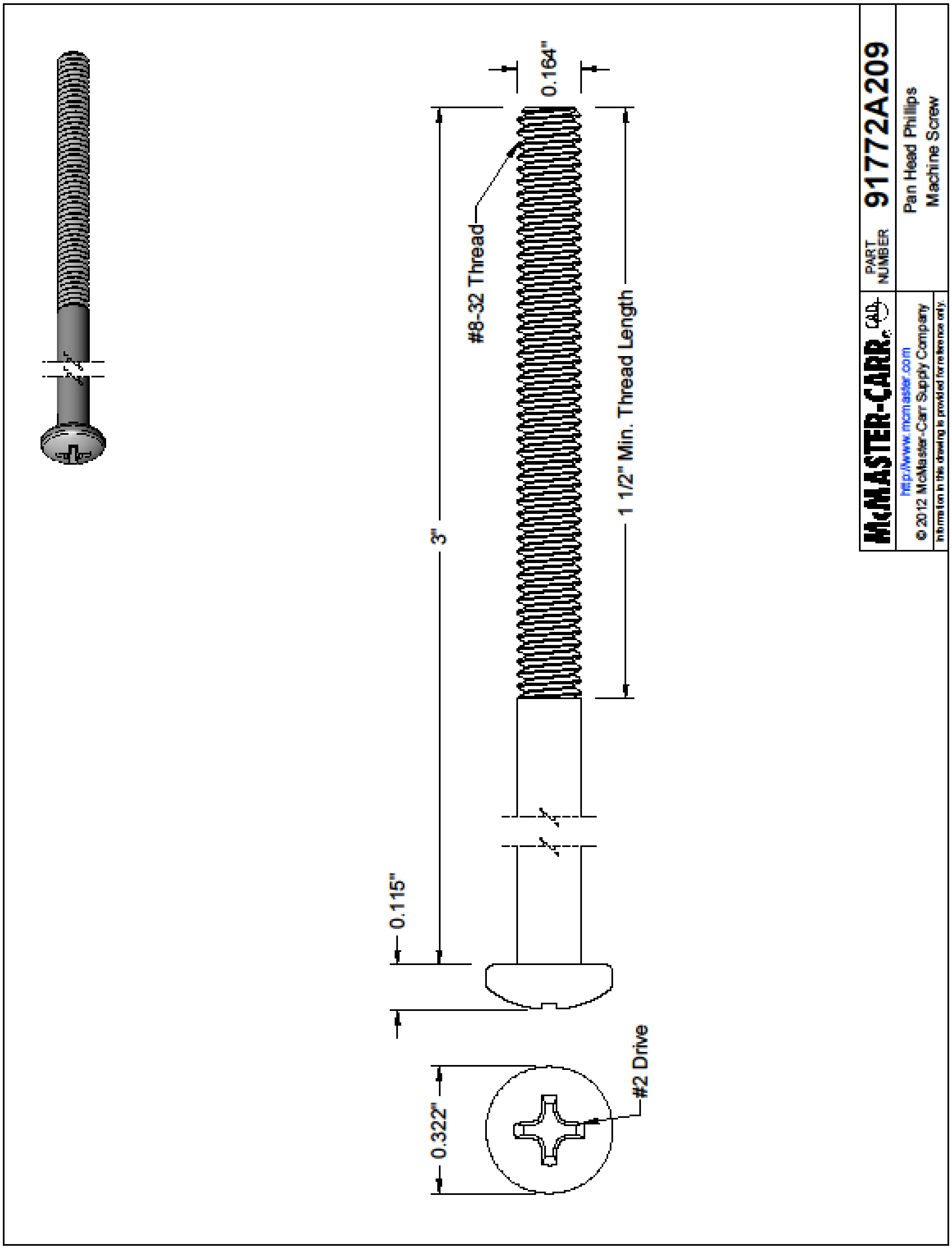
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1 1/2" Min. Thread Length
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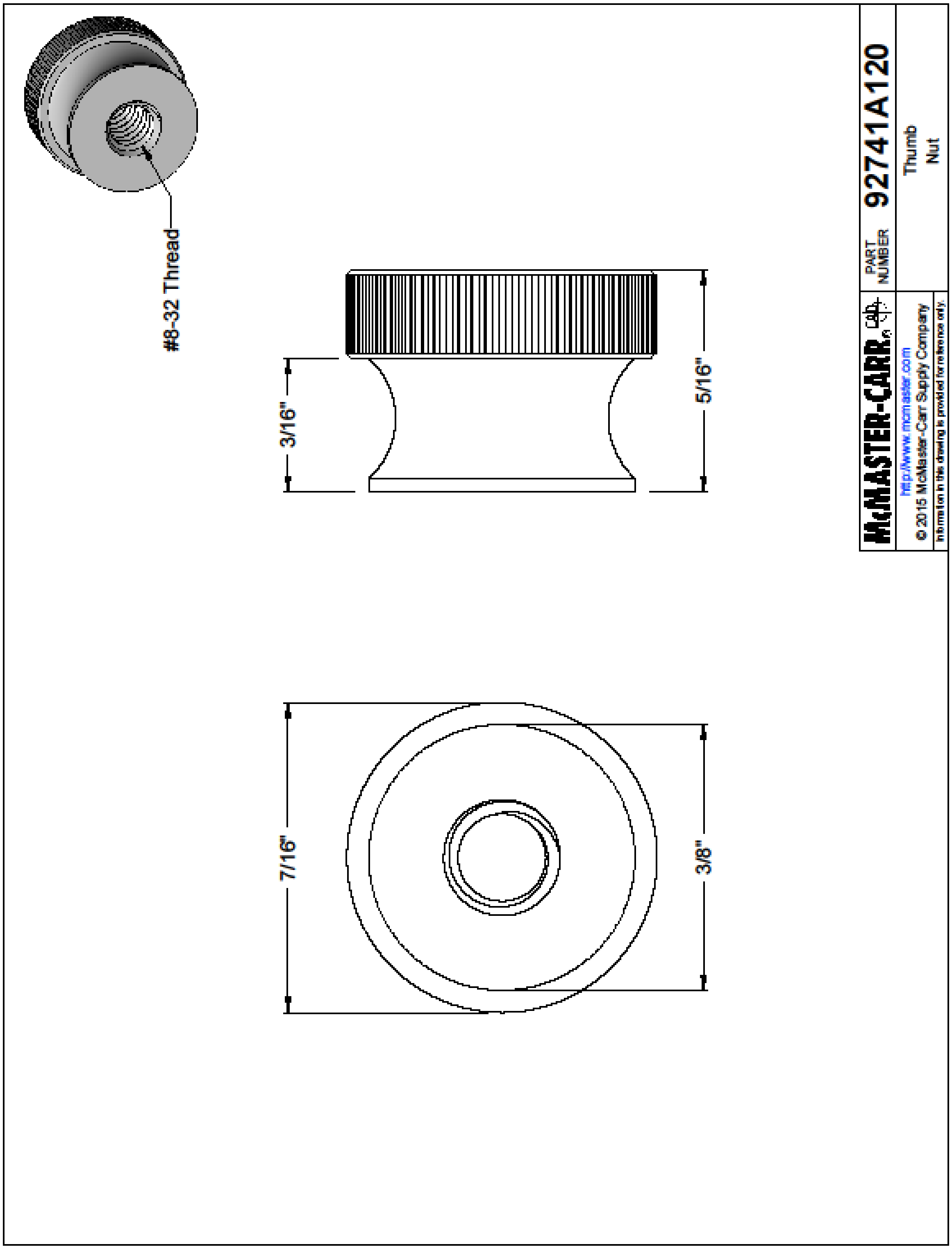
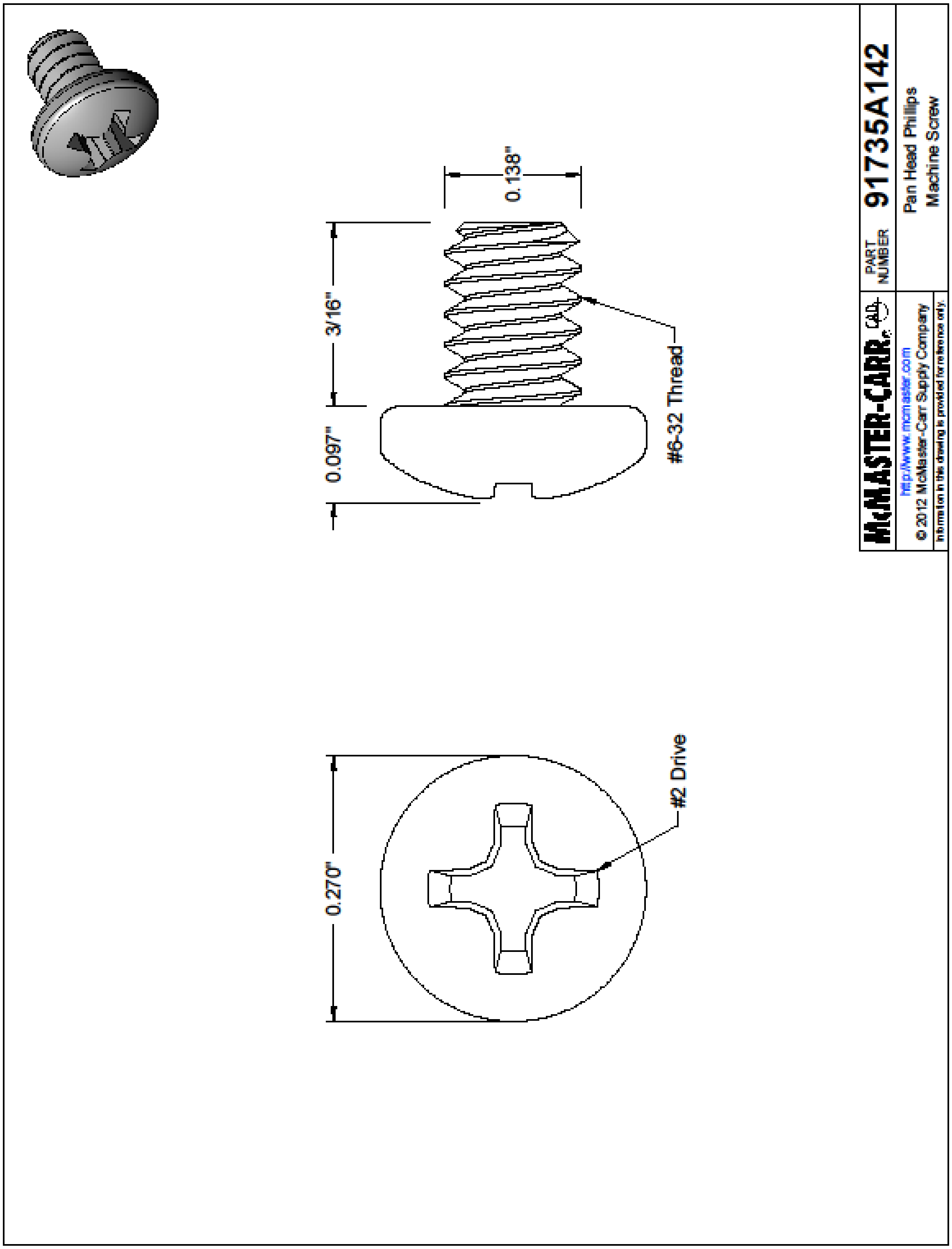
0.322"
#2 Drive
McMASTER-CARR
CAD
http://www.mcmaster.com
© 2012 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER
91772A209
Pan Head Phillips
Machine Screw


#8-32 Thread
3/16"
5/16"
7/16"
3/8"
McMASTER-CARR
http://www.mcmaster.com
© 2015 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER
92741A120
Thumb
Nut


0.138"
3/16"
0.097"
#6-32 Thread
0.270"
#2 Drive
McMASTER-CARR
CAD
PART NUMBER
91735A142
Pan Head Phillips
Machine Screw
http://www.mcmaster.com
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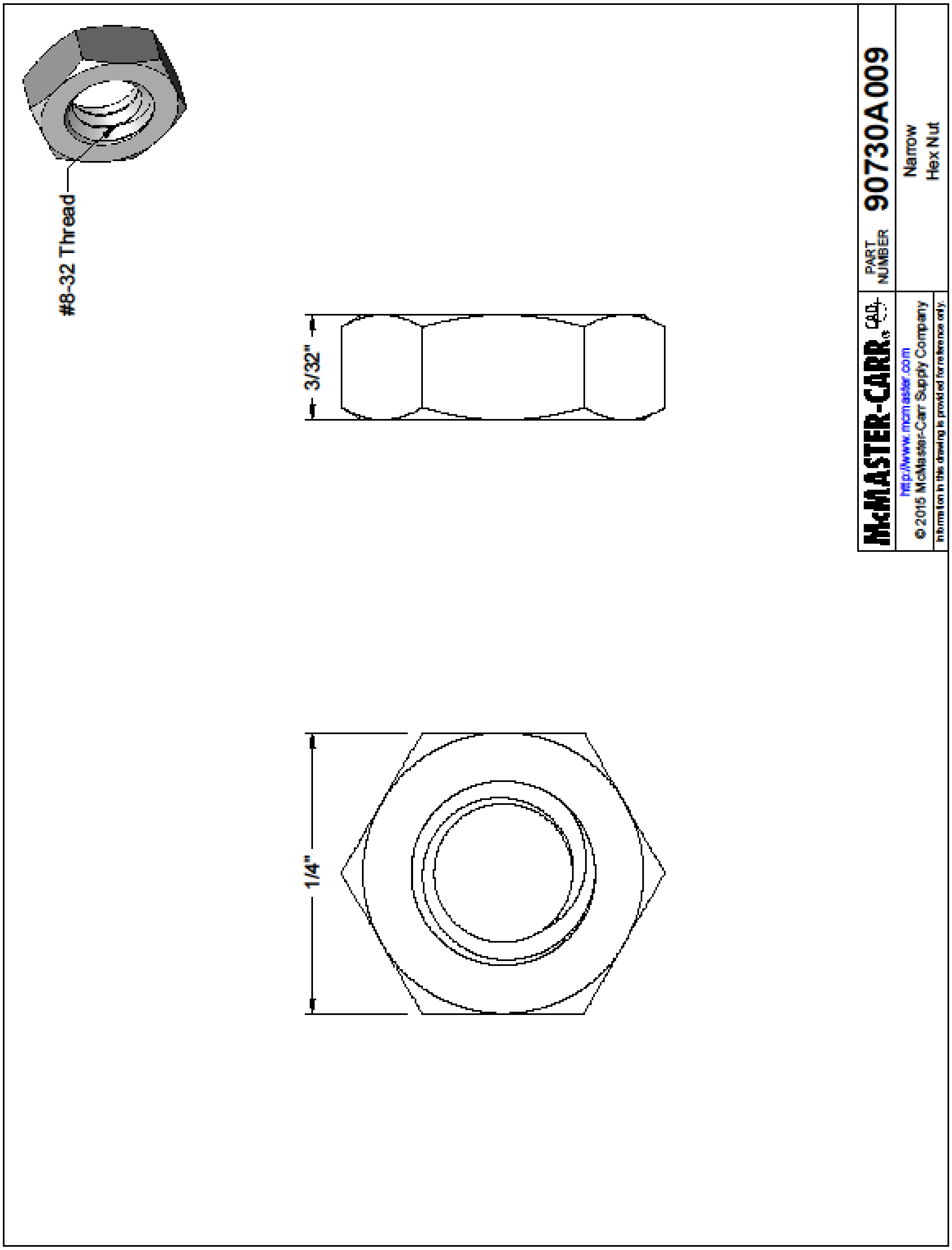
#8-32 Thread
3/32"
1/4"
McMASTER-CARR
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Information in this drawing is provided for reference only.
PART NUMBER
90730A009
Narrow
Hex Nut

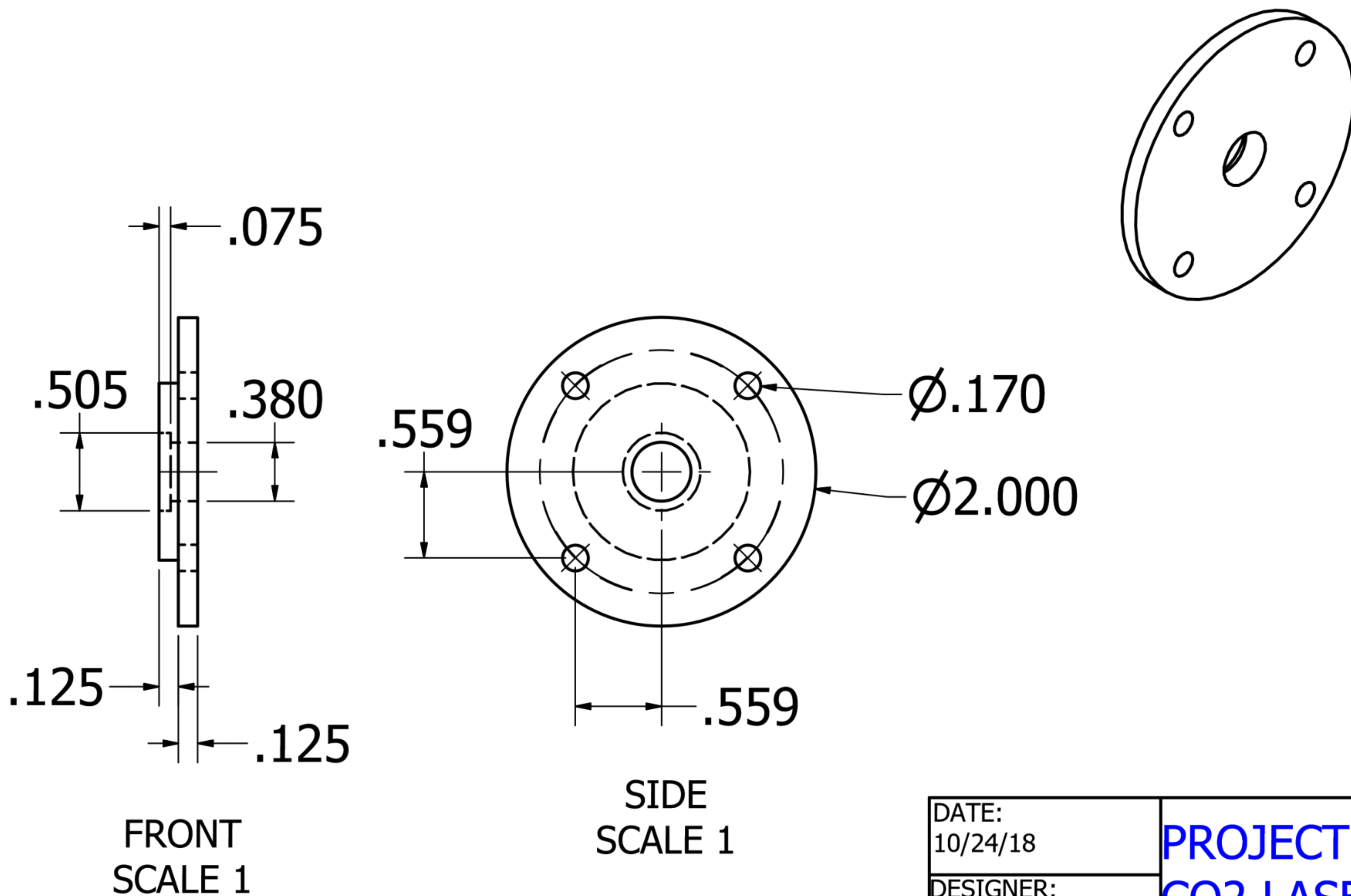
Oring Specifications:

1. Oring Large:

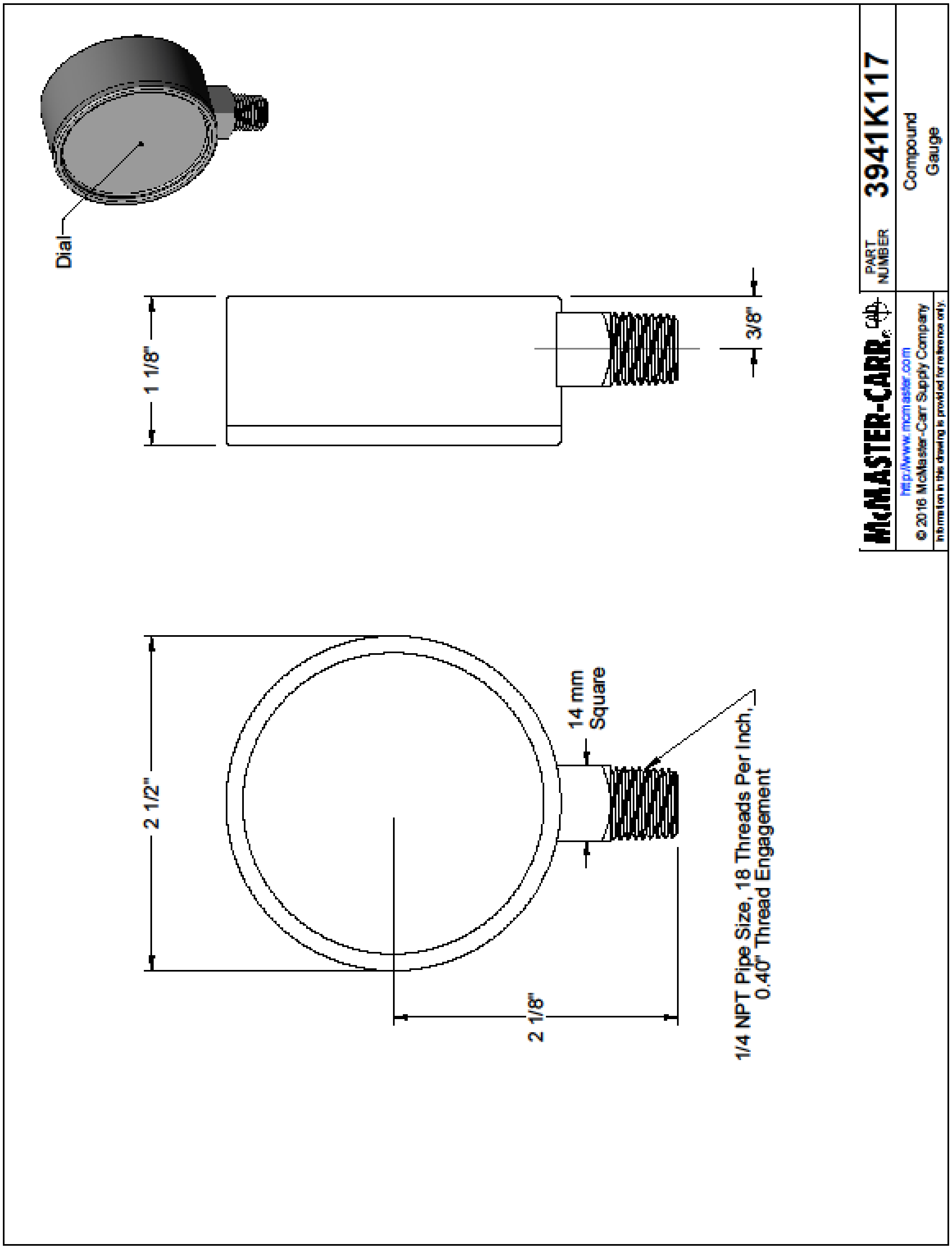
Material	Silicone Rubber
Cross Section Shape	Round
Dash Number	112
Fractional	
Width	3/32
ID	1/2
OD	11/16
Actual	
Width	0.103"
ID	0.487"
OD	0.693"
Hardness	Durometer 70A (Medium)

2. Oring Small:

Material	Silicone Rubber
Cross Section Shape	Square
Dash Number	012
Fractional	
Width	1/16
ID	3/8
OD	1/2
Actual	
Width	0.07"
ID	0.364"
OD	0.504"
Hardness	Durometer 70A (Medium)



DATE: 10/24/18	PROJECT: CO2 LASER Mk. 3
DESIGNER: Jacob	
STOCK NUMBER:	
PART NAME: Optics Adj. Plate	MATERIAL: ABS Plastic


Dial
1 1/8"
3/8"
2 1/2"
14 mm
Square
2 1/8"
1/4 NPT Pipe Size, 18 Threads Per Inch,
0.40" Thread Engagement
McMASTER-CARR
http://www.mcmaster.com
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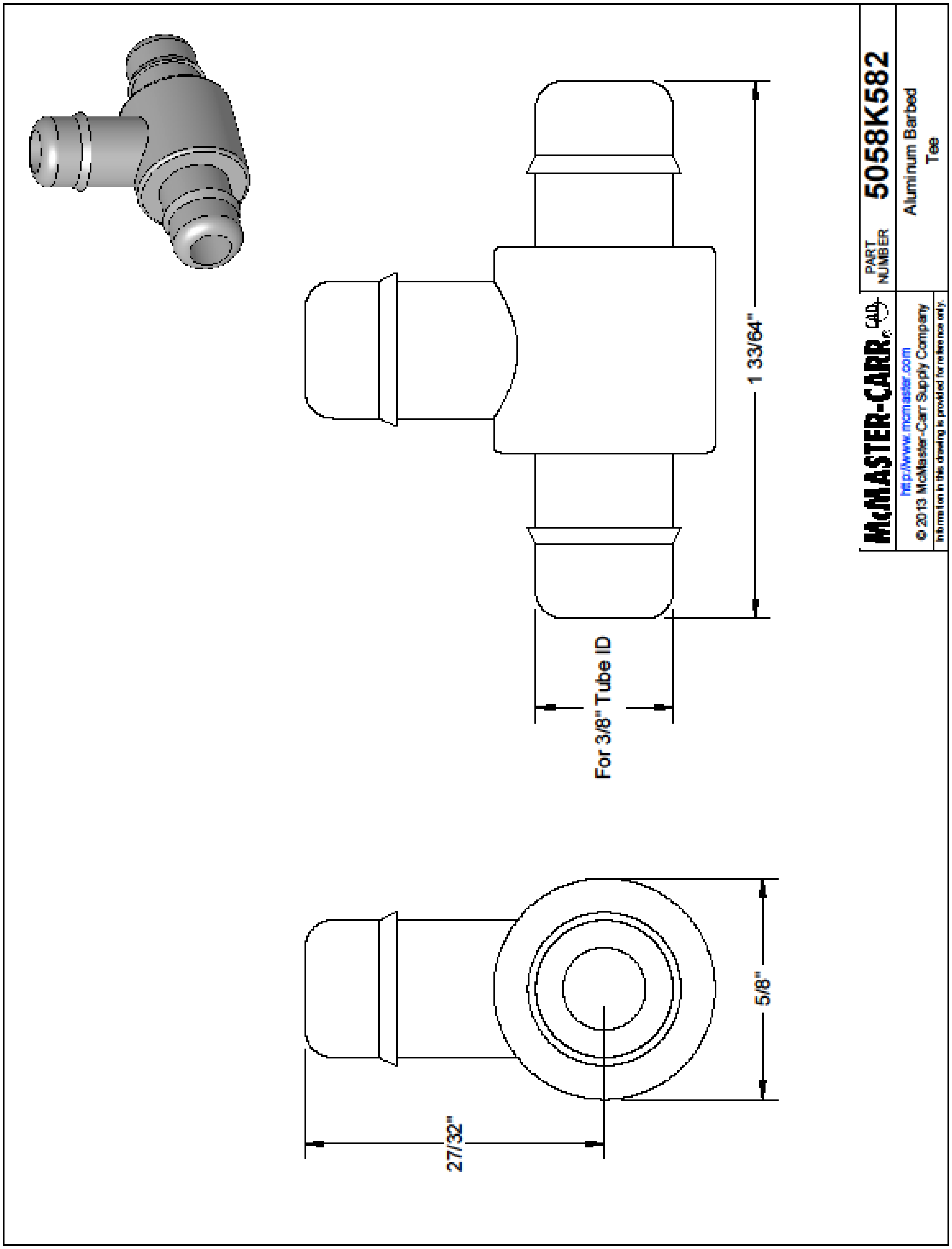
Information in this drawing is provided for reference only.
PART NUMBER
3941K117
Compound
Gauge


1 33/64"
For 3/8" Tube ID
5/8"
27/32"
McMASTER-CARR
CAD
http://www.mcmaster.com
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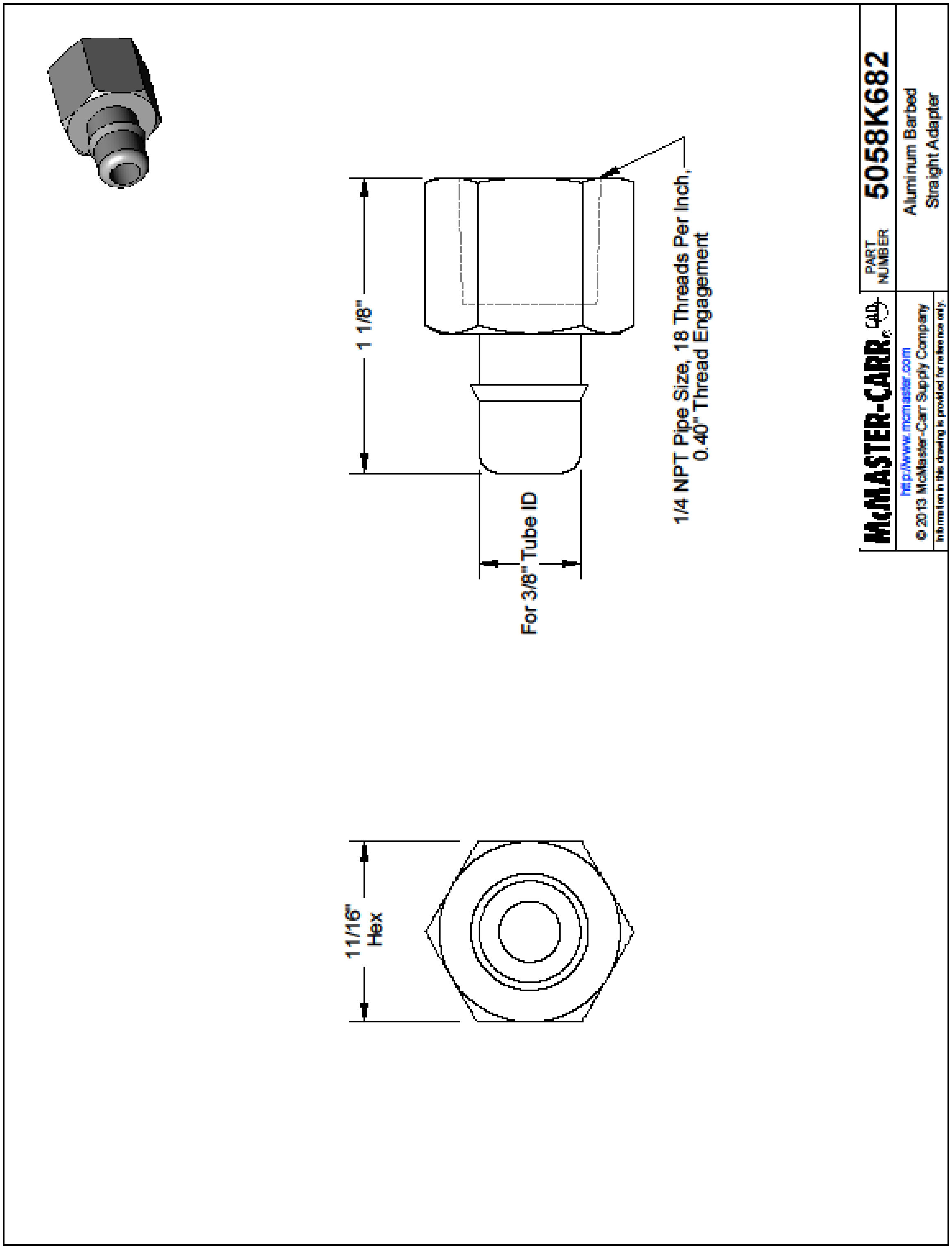
Information in this drawing is provided for reference only.
PART NUMBER
5058K582
Aluminum Barbed Tee



1 1/8"
1/4 NPT Pipe Size, 18 Threads Per Inch,
0.40" Thread Engagement
For 3/8" Tube ID
11/16"
Hex
McMASTER-CARR
CAD
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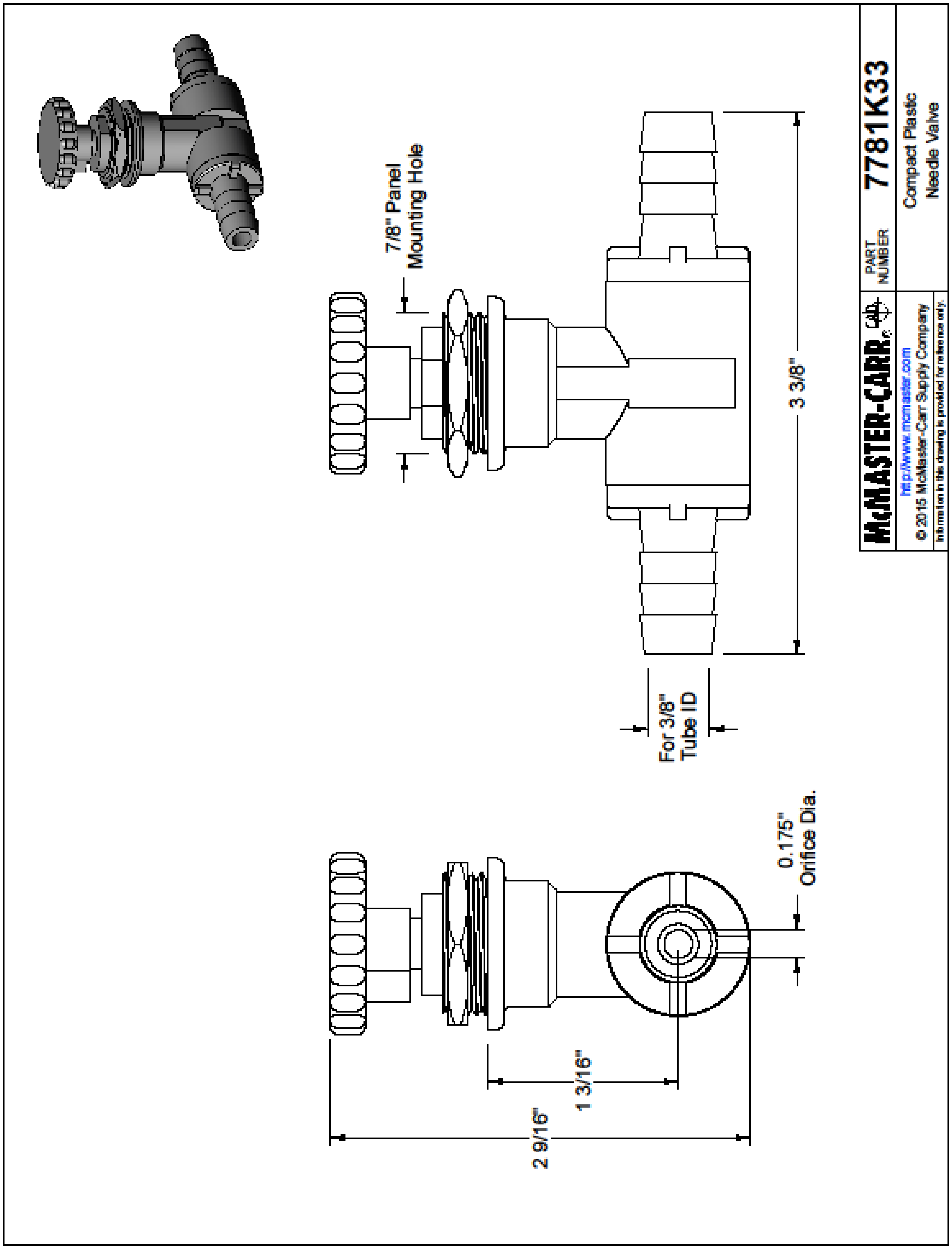
Information in this drawing is provided for reference only.
PART NUMBER
5058K682
Aluminum Barbed
Straight Adapter



7/8" Panel
Mounting Hole
3 3/8"
For 3/8"
Tube ID
0.175"
Orifice Dia.
1 3/16"
2 9/16"
McMASTER-CARR
http://www.mcmaster.com
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PART NUMBER
7781K33
Compact Plastic
Needle Valve

Specifications

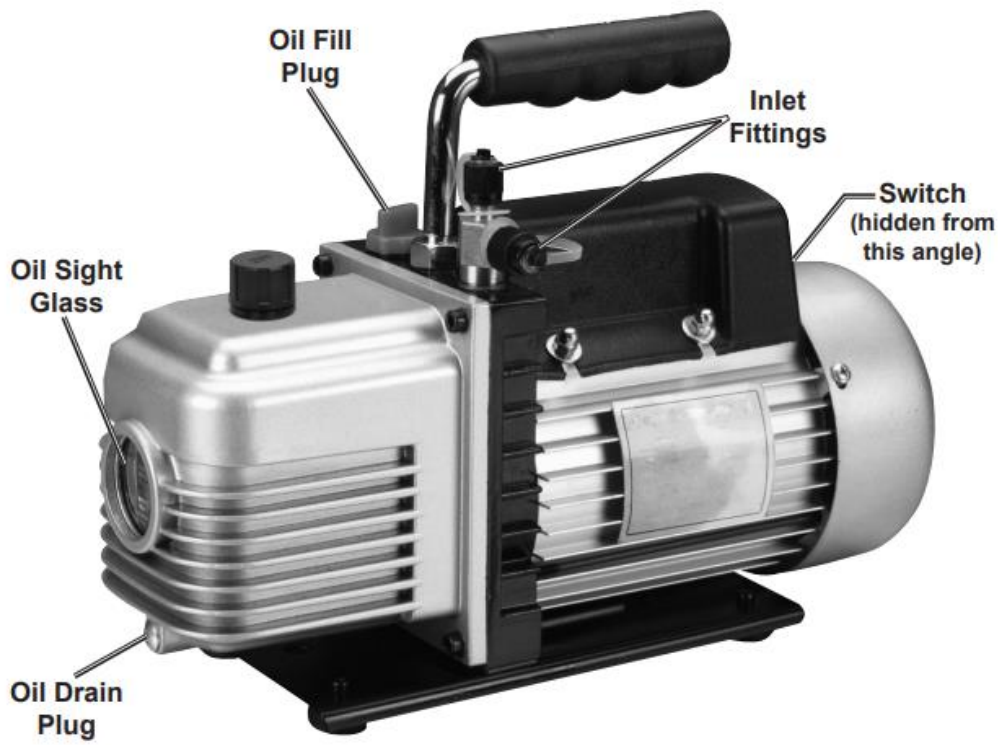
Electrical Rating	120 V~ / 60 Hz / 5 A
Air Displacement	3 CFM
Fittings	R134A and R12/R22
Ultimate Vacuum	22.5 micron (3 Pascal)
Oil Capacity	6.8 Ounces (200 ml)
Working Pressure	15 PSI

US
231672
VE225

Setup - Before Use:

Read the ENTIRE IMPORTANT SAFETY INFORMATION section at the beginning of this manual including all text under subheadings therein before set up or use of this product.

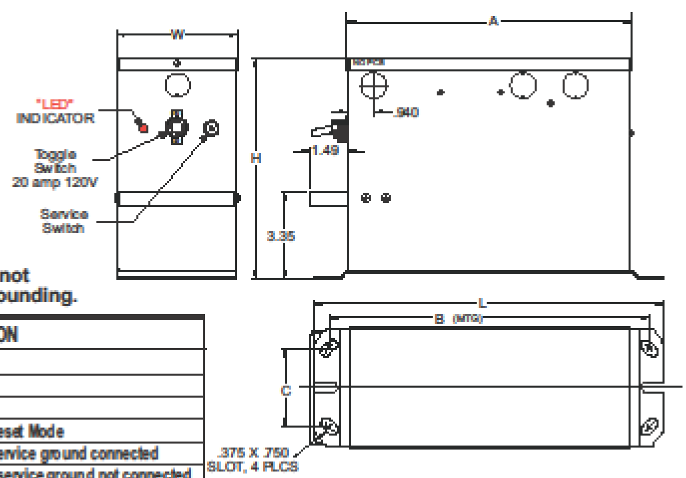
Functions



Power Supply Specifications

P5KA2NG-2E Series

NORMAL POWER FACTOR													
Catalog Number	VAC	Hz	Secondary		Primary	Input	Wt.	Case Dimensions					
			Volts	mA	V.A.	Amp.	Lbs.	L	W	H	A	B	C
15030 P5KA2NG-2E	120	60	15000	30	435	3.60	25	13.35	4.50	7.42	10.87	12.21	3.0
12030 P5KA2NG-2E	120	60	12000	30	380	3.15	23	13.35	4.50	7.42	10.87	12.21	3.0
10530 P5KA2NG-2E	120	60	10530	30	310	2.55	23	13.35	4.50	7.42	10.87	12.21	3.0
9030 P5KA2NG-2E	120	60	9000	30	285	2.35	19	13.35	4.50	7.42	10.87	12.21	3.0
7530 P5KA2NG-2E	120	60	7500	30	250	2.10	17	13.35	4.00	6.13	10.87	12.21	3.0
6030 P5KA2NG-2E	120	60	6000	30	200	1.65	16	13.35	4.00	6.13	10.87	12.21	3.0
5030 P5KA2NG-2E	120	60	5000	30	170	1.40	16	13.35	4.00	6.13	10.87	12.21	3.0
4030 P5KA2NG-2E	120	60	4000	30	140	1.15	15	13.35	4.00	6.13	10.87	12.21	3.0
15060 P5KA2NG-2E	120	60	15000	60	900	7.50	30	14.85	5.50	8.47	12.37	13.71	3.0
12060 P5KA2NG-2E	120	60	12000	60	720	6.00	29	14.85	5.50	8.47	12.37	13.71	3.0
9060 P5KA2NG-2E	120	60	9000	60	565	4.70	27	13.35	4.50	7.42	10.87	12.21	3.0
7560 P5KA2NG-2E	120	60	7500	60	460	3.85	25	13.35	4.50	7.42	10.87	12.21	3.0
15030 P5KA2NG-2E	277	60	15000	30	425	1.55	25	13.35	4.50	7.42	10.87	12.21	3.0
12030 P5KA2NG-2E	277	60	12000	30	385	1.40	23	13.35	4.50	7.42	10.87	12.21	3.0
10530 P5KA2NG-2E	277	60	10530	30	310	1.15	23	13.35	4.50	7.42	10.87	12.21	3.0
9030 P5KA2NG-2E	277	60	9000	30	275	1.00	19	13.35	4.50	7.42	10.87	12.21	3.0
7530 P5KA2NG-2E	277	60	7500	30	235	.85	17	13.35	4.00	6.13	10.87	12.21	3.0
6030 P5KA2NG-2E	277	60	6000	30	190	.70	16	13.35	4.00	6.13	10.87	12.21	3.0
5030 P5KA2NG-2E	277	60	5000	30	160	.60	16	13.35	4.00	6.13	10.87	12.21	3.0
4030 P5KA2NG-2E	277	60	4000	30	130	.50	15	13.35	4.00	6.13	10.87	12.21	3.0



Service Switch does not operate without proper grounding.

DIAGNOSTIC LED OPERATION	
LED Fault Code	Indicates
Steady ON	Operating normally
Continuous Flashing	In Service Mode
1 - Flash	15 second Diagnostic & Auto Reset Mode
2 - Flash	Secondary Ground Fault with service ground connected
3 - Flash	Secondary Ground Fault when service ground not connected
4 - Flash	Input Voltage exceeds 120% of rated
5 - Flash	Line & Neutral reversed on input connections

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xs090050 4/29/09

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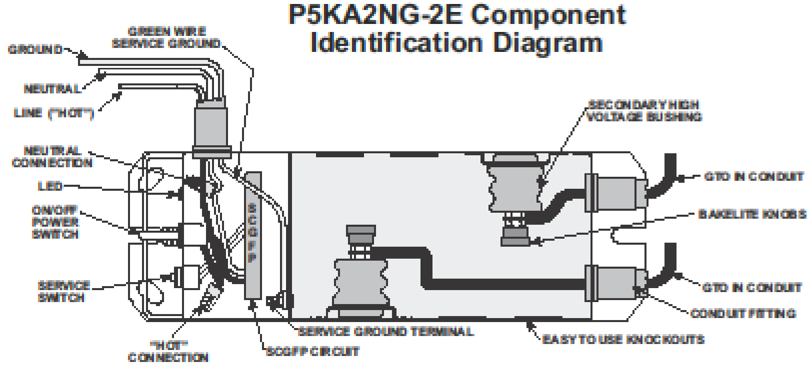
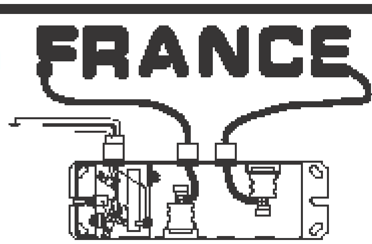
P5KA2NG-2E
P5KA2NCG-2E

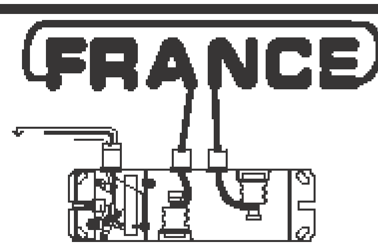
P5KA2NG-2E Component Identification Diagram



Standard Series Wiring Method:
(Please read instructions on reverse)



Virtually-Grounded Series Wiring Method:
(Please read instructions on reverse)



When will a Secondary-Circuit Ground Fault Protection P5KA2NG-2E Series Transformer NOT trip:

- Ground faults on the primary (line) side of the transformer. **Secondary-Circuit Ground-Fault Protected Transformers will NOT provide protection against electrical shock.**
- Series arcs in the sign system (arcs associated with defective tubing interconnections or between sign tubing sections).
- Breaks in the sign tubing, degassed tubing, or opens in the high voltage connections without a corresponding short or arc to ground.
- Shorts to an ungrounded metal part within or near a sign.

NEON TRANSFORMER WITH UL2161 COMPLIANT SERVICE SWITCH

A push button style service switch is located on the end of the primary wiring compartment. To activate service mode: while the transformer is on, depress and hold the switch for 1 second and release. The tubing will flash on 3 times to indicate the transformer is in service mode (SCGFP circuit is disabled). The tubing should then remain on. The tube may not light if the tube is broken or shorted. The LED will constantly flash while unit is in service mode. The unit remains in service mode for 29 minutes. After 29 minutes, the unit will return to normal mode. To escape service mode before the 29 minutes has elasped, depress the service switch and hold for 1 second and release, or turn power off, wait 3 seconds, then turn power on. The unit will restart in normal mode.

LUMINOUS TUBE FOOTAGE CHART

TRANSFORMER RATING		Approximate Number of Feet of Tubing Operated[1]																
Secondary Voltage V	Short-Circuit Current mA	Clear or Fluorescent Red Neon (Also Recommended for Neon Fluorescent Gold) Tube Size, Millimeters								Clear or Fluorescent Mercury Filled Tubes All Colors (All Enclosed Applications)[2] Tube Size, Millimeters								Secondary Voltage V
		18	15	14	13	12	11	10	9	18	15	14	13	12	11	10	9	
15,000	30/60	72	60	54	50	45	40	36	32	80	72	64	60	54	48	44	39	15,000
12,000	30/60	55	45	42	39	35	32	29	26	62	55	50	46	42	38	35	31	12,000
10,500	30	48	39	36	34	31	28	25	22	54	48	43	40	37	33	30	27	10,500
9,000	30/60	40	33	30	29	26	24	21	18	45	40	36	33	31	26	25	22	9,000
7,500	30/60	28	26	24	22	21	19	17	15	35	31	28	27	25	23	20	18	7,500
6,000	30	23	20	19	18	16	15	13	12	26	24	23	21	19	18	16	14	6,000
5,000	30	19	17	16	15	12	11	10	8	23	20	19	16	15	13	12	10	5,000
4,000	30	16	13	12	11	10	9	8	7	19	16	14	13	12	10	9	8	4,000
Recommended Gas Pressure mmHg		8	9	10	10	11	12	13	15	8	9	10	10	11	12	13	15	

(1) Based on average grade. (2) All enclosed applications. Exposed and extremely cold climates may require footage be reduced by 10-20%.
NOTE 1: Deduct approximately 1 foot from above figures for each pair of electrodes.
NOTE 2: Recommended gas pressure for 10-ft plus lengths. Increase 10% for tube lengths under 10 ft.

Optics Alignment

Perfectly aligned optics are imperative to the operation of this laser. Since the beam of light may be resonated thousands of times before it exits the laser, any slight mis-alignment will result in drastic losses. For this laser to emit any detectable output, the optics must be perfectly aligned.

Described in this section is a method to accurately align the output coupler and surface mirror at either end of the laser tube. A secondary laser is necessary for this alignment method. The steps for aligning the optics are as follows:

1. Remove the 3D printed alignment plates from both ends of the laser tube. The secondary laser beam should be able to travel straight through the laser tube unblocked.
2. Find a textbook of sufficient width to place the secondary laser pointer on. The secondary laser pointer must be placed at a height such that the beam can travel straight through the middle of the laser tube. The best way to place the secondary laser pointer at the correct height is to use a textbook that isn't wide enough and wedge sheets of copy paper between the secondary laser pointer and the textbook until the height is just right. Leave about a foot of space between the edge of the textbook and the laser tube.
3. Take an index card and bend it so that it stands. Poke a tiny hole in the index card that is at the exact height of the secondary laser pointer beam.
4. Place the cardboard target in between the output of the secondary laser pointer and the front end of the laser tube. The beam from the secondary laser pointer should shine straight through the pinhole in the cardboard target and through the laser tube. Make sure the white part of the cardboard is facing the laser tube and not secondary laser pointer.
5. With the beam of the secondary laser pointer traveling straight through the laser tube, the mirror at the closed end of the laser can be installed and aligned.
6. With the alignment plate pressed up against the mirror, the four adjustment screws can be used to make slight changes to the angle of the alignment place and mirror. Adjust the mirror until a red dot (from the laser beam being reflected) is visible on the white surface of the cardboard. Continue to adjust the laser until the red dot can travel straight through the pinhole on the cardboard from which it initially came through.
7. Repeat the process with the output coupler.
8. With the alignment laser still in place, turn on the vacuum pump and bring the pressure inside the tube to as low as possible. Ensure the optics are still aligned under vacuum pressure and make any adjustments even if the alignment changes are slight.

Operating the Completed Laser

General Safety Precautions

A CO2 laser outputs a beam that has a theoretical output wavelength of 10.6 micrometers. At this wavelength, glass and polycarbonate – both transparent to visible light – are opaque. As a result, both materials will absorb the beam and melt. The emitted beam is completely invisible to the human eye. Furthermore, the laser is pumped with a high voltage power supply that outputs lethal amounts of current at extremely high voltages. As such, safety precautions must be taken.

Notes on Proper Eyewear

To avoid permanent and severe damage to the eyes, proper eyewear must always be worn when operating the laser. For a low powered homebuilt CO2 laser, safety glasses made from tempered glass or polycarbonate can suffice. Ensure that the safety glasses are made from glass or polycarbonate as not all clear plastics fully absorb the output. While safety glasses can be used for some lower powered CO2 lasers, laser glasses that are rated and certified should always be used when operating a CO2 laser.

Notes on Safe Operation of High Voltage Devices

The power supply that is used to pump the laser outputs 30 milliamps – more than enough to kill the average human. Included below is a list of safety precautions to be taken while operating a high voltage device:

- Construct a discharge rod. Obtain a handle that is about 2-3 feet and made of an insulative material such as wood or PVC pipe. At the end of the handle, attach a piece of conductive material such as a steel ball or a folded piece of uncoated hanger wire. This discharge rod should be used to discharge areas of the laser that are likely to have a buildup of static charge by touching the conductive end of the rod to the charged area. Possibly charged areas include the adjustment screws and gas port tube.
- Ensure the power supply and metal laser stand are properly grounded. In the case of this laser, the ground must be connected to a three-pronged outlet that is connected directly to earth ground.
- Keeping one’s left hand in their pocket will decrease the chance that an electric shock travels through the heart.
- Wear insulative gloves and rubber soled shoes. Work on a floorspace made of an insulative material such as wood, rubber, or concrete.
- Never operate the laser if the air is excessively humid.

Constructing a Beam Stop

The beam emitted from a CO_2 laser is invisible to the naked eye and has the potential to burn skin on contact and blind eyes in fractions of a second. This applies not only to the beam emitted directly from the laser tube but also to reflections. The purpose of a beam stop is to absorb both the direct and stray laser rays to prevent damage or injury to surrounding structures or people.

A beam stop can be constructed from an aluminum box with a black painted inside. The only opening to the box should be small hole on the side of the box to contain as many reflected rays as possible. The black coating on the inside of the box will help to absorb as much of the light as possible while the aluminum itself will act as heatsink to diffuse the heat released as the beam is absorbed.

Notes on Obtaining and Using a Proper Gas Mixture

The CO_2 laser runs on a mixture of CO_2 and Nitrogen. Both gases are necessary for the laser to run. However, adding helium to the gas mixture greatly enhances the performance of the laser. The optimal ratio of the three gases varies between different CO_2 lasers and requires tweaking. The optimal gas mixture is roughly 10% CO_2, 20% nitrogen, and the rest helium by volume.

To optimize efficiency and laser output, an industrial grade supply of CO_2 laser gas mixture should be used. However, the laser can be made to function using impure gas supplies and a relatively inaccurate gas mixture made at home. The method for obtaining and mixing the gases at home is described below.

Obtaining supplies of the CO_2, nitrogen, and helium is not prohibitive or expensive. Although the sources of gas will not yield pure results, they can sometimes suffice for a homebuilt laser. The helium used for the mixture can be easily obtained from a balloon fill kit found at stores like Target and Walmart. The balloon fill canister usually contains 80% helium and 20% air. The CO_2 supply can be obtained by reacting baking soda and vinegar and capturing the resultant gas, CO_2. Alternatively, the CO_2 can be obtained directly from capturing human exhale or from a small CO_2 cannister used to refill bicycle tires and power pellet guns. Of the three methods described, using CO_2 from a cannister will yield the best results as the CO_2 sourced from exhale and the baking soda and vinegar reaction contain water vapor. The nitrogen can be obtained by directly using air, which is composed of about 70% nitrogen.

To create the gas mixture, partially fill the balloon with a small amount CO_2 and measure the circumference. Calculate the volume of the balloon as if it were a sphere to make the calculation easier. Multiply that volume by 3 and solve for the new circumference at that volume. Now fill the balloon with nitrogen until that new circumference is reached. Finally, repeat the steps above, but multiply the volume by 3.3 instead of 3.

Operation Sequence

To operate the CO_2 laser, a specific set of steps must be completed sequentially to ensure proper laser function and safety. The steps below must be completed in order.

1. Check the entire laser system. Each of the following statements must be true:
    - The vacuum pump, power supply, fish tank pump, and power strip are switched off.
    - The power supply is properly grounded, and all electrical connections are insulated.
    - All valves are fully closed
    - All plastic vacuum, gas, and water-cooling tubing is attached securely.
    - A proper beam stop is placed directly in the path of laser beam to be emitted.
2. Plug the power strip into the wall socket and plug the fish tank pump into the power strip. Turn on the power strip to turn on the fish tank pump and start the water-cooling system before the laser is operated. Allow the water-cooling chamber to fill with water and check for leaks. Because the water coolant and the plasma discharge inside the laser tube are separated only by a thin wall of glass, there is a chance the water coolant can become electrified if something is not properly insulated. Any leaks in the water-cooling system could become high voltage wires and pose a safety threat.
3. Plug the vacuum pump into the power strip and partially open the larger ball valve. Now turn on the vacuum pump to begin creating the vacuum environment inside the laser tube.
4. Plug the power supply into the power strip and turn it on. A purple plasma should appear along the entire length of the laser tube.
5. Slowly adjust the needle valve to allow gas mixture to flow into the tube. Be careful not to do this step too fast or too much gas will flow through the laser tube and raise the pressure too high to sustain the plasma discharge. Lasing should occur during this step.
6. To power down the laser, turn the power supply off. Allow the vacuum pump to remove any gas mixture that may be left inside the laser tube from operation and then close the needle valve.
7. Turn the vacuum pump off and turn the power strip off. Close the ball valve.
8. Unplug the fish tank pump, power supply, and vacuum pump from the power strip and unplug the power strip from the wall outlet.
9. To empty the excess water from the water-cooling jacket, disconnect everything from the laser tube and manually angle the laser tube to empty any excess water left inside.

Method for Fabricating the Output Coupler and Surface Mirror

To maintain the optical resonance necessary for the system to lase, the laser tube must have surface mirrors at either end. The mirrors cannot have a reflective surface under a layer of glass as the light emitted will not travel through the glass and will instead melt it. Therefore, the reflective part of mirror must be exposed. To accomplish this, mirrors can be fabricated out of polished copper blanks.

This method for fabricating the surface mirrors uses solid copper pennies minted before 1983 (the first year that pennies were switched from solid copper to copper-plated zinc) as the mirror blanks. The steps for this method are as follows:

1. Obtain pure copper pennies made before 1983. Using a small dab of superglue, glue the penny onto a small, flat piece of wood.
2. Using sandpaper or a belt grinder, grind down the emblem on the penny until one side is perfectly flat and free of any markings. Start with a course sandpaper such as 80 grit and progress to 600 grit or finer. This side of the penny will become the mirror surface.
3. Using a silver polish (salt and vinegar also works), clean the mirror surface of the penny until it is as bright and shiny as possible.
4. Obtain a cotton tee-shirt and fine polishing compound. Using a side to side motion, complete the surface mirror by polishing the mirror surface until it is perfectly reflective. Be sure to rotate the penny to ensure all parts of the mirror surface are equally polished. It is best to perform this step gently and over an extended period to ensure the mirror surface does not scratch.
5. To make the output coupler take the completed surface mirror and drill a small hole through its center. The hole must be perfectly centered. The size of the hole roughly corresponds to the reflectivity rate of the output coupler.
6. The hole in the mirror must be sealed with a material, such as sodium chloride (table salt), that is able to transmit the wavelength of light that will be emitted by the laser. A salt lens must be fabricated and fixed over the hole in the surface mirror to complete the output coupler. To make the lens, obtain a supply of ice cream salt. Used for ice cream machines, the salt crystals are in large chunks and can be used to make a lens. Choose a chunk of salt and use fine sand paper to grind it into a thin perfectly flat disc shape. Use the polishing compound and cotton tee-shirt to polish the salt disc. The finished salt lens should be perfectly transparent and have no fracture lines visible near the center.
7. To complete the output coupler, place the salt lens over the hole of the unfinished side of the surface mirror and use epoxy around the edges to create an airtight seal. Take care not allow any epoxy to spill over the center of the lens.

Sources

Vendors and Stores

1. Wale Apparatus; specializes in glass fabrication equipment (glass cutter and Kevlar gloves) and glass parts (discharge tube). The glassware was packaged very well, and their customer service is excellent.

2. McMaster Carr; specializes in industrial parts, materials, and equipment (tubes, connectors, vacuum gauge, etc.). Provides extensive documentation for each part. Excellent customer service and fast very fast shipping.

3. Information Unlimited; specializes in hard to find electronic parts. Great source for high voltage applications.

4. Harbor Freight Tools; specializes in discount tools and machinery (vacuum pump). The quality of their products is very decent when the low price is taken into consideration.

5. Meredith Instruments; discount and surplus lasers, equipment, and parts.

6. Laser Research Optics; supplier of CO2 laser optics. Has a dedicated section for used and overrun optics at a significantly lower price.

Information and Research

1. http://jarrodkinsey.org/co2laser/co2laser.html

   Details the construction of a homebuilt CO2 laser. Includes the method of fabricating the mirrors from pennies, provides information regarding optimal operating pressure, power supply voltage based on pressure, and gas mixture ratios.

2. http://technology.niagarac.on.ca/people/mcsele/lasers/index.html

   Major source for information regarding the mechanics behind laser operation. Also contains extensive material on many other types of lasers.

3. https://www.repairfaq.org/sam/laserco2.htm

   Extensive material covering every aspect of CO2 laser mechanics, construction, and operation. Also contains extensive material covering safety precautions to take when operating a CO2 laser.