The fun and easy way® to prepare, compress, and heat a cell assembly

Piston Cylinder Experiments FOR DUMMIES®

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Jack Sheehan
Mineral Physicist

Harvard Mineral Physics
PISTON CYLINDER

Geophysics is no longer a field for uncontrolled speculation.

—Sir Harold Jeffreys, 1924

This manual is dedicated to those who continue to speculate uncontrollably about geophysics and make use of this piston cylinder apparatus to do so.

Harvard Mineral Physics
PISTON CYLINDER

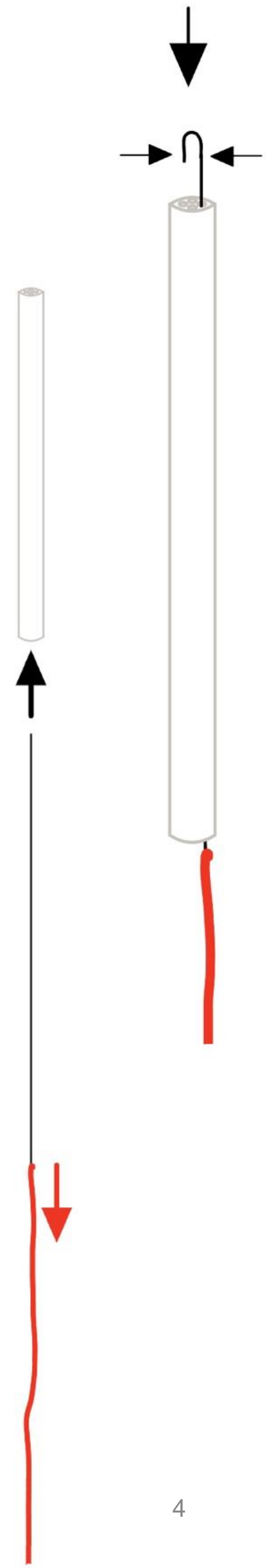
Table of Contents

1. Preparing the Cell Assembly

1.1 Making the Thermocouple

1.1.1 What you need:

- 2.2-inch Alumina (Al_2O_3) rod with four pre-drilled holes
- DATAQ acquisition kit (use the red and white wires)
- Caliper, tweezers, sandpaper (150 grit)



1.1.2 What to do:

- Sand the rod to ~2.15 in using the sandpaper. The exact length varies but should be the length of thermocouple MgO rod in cell assembly (~0.5 in) + 0.5 in for the base plug + 1 in for thermocouple plate + ~0.15 excess to stick out the top. Be careful not to snap the rod while sanding!
- Push the wire cover back until 3–4 inches of wire are exposed
- Run the wire through one of the four holes in the Al rod until ~1 in of wire is exposed through the end of the rod
- Using the tweezers, squeeze the final ~3 mm of exposed wire and rotate 90º to make a hook. Squeeze the hook towards the main wire so that the hook is straight.
- Pull the wire back down through the rod, until the hooked wire fits into the hole opposite the hole that the wire currently goes through. This may take some small adjustments with the tweezers and several attempts—don't worry!
- Repeat with the other wire and the two remaining holes
- Upon completion, the two wires should cross each other and be firmly touching in an X pattern. The wire covers should completely cover the rest of the exposed wires so that they cannot touch. The other end of each wire must also be screwed in between the washers behind the caps: red wire behind red cap, and white wire behind white cap.

1. Preparing the Cell Assembly

1.2 Testing the Thermocouple

1.2.1 What you need:

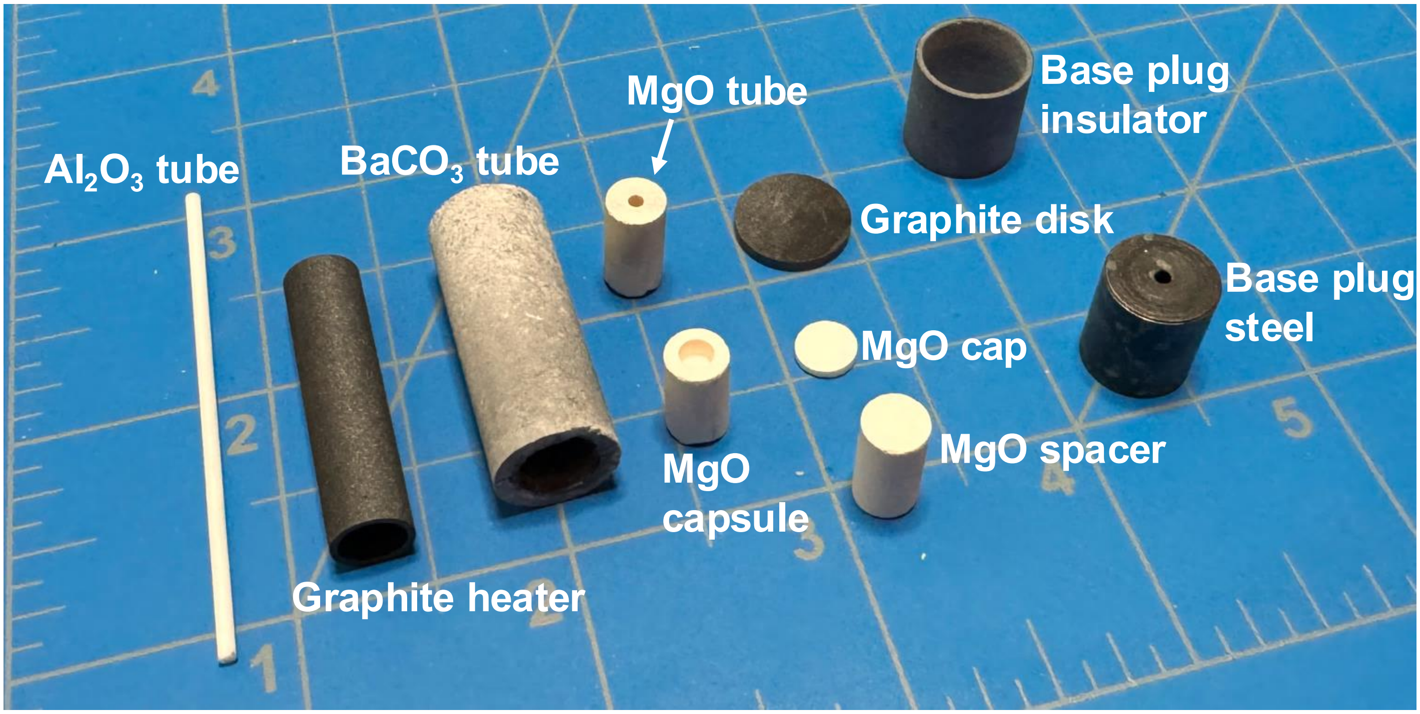
- Completed thermocouple connected to DATAQ acquisition kit
- Computer

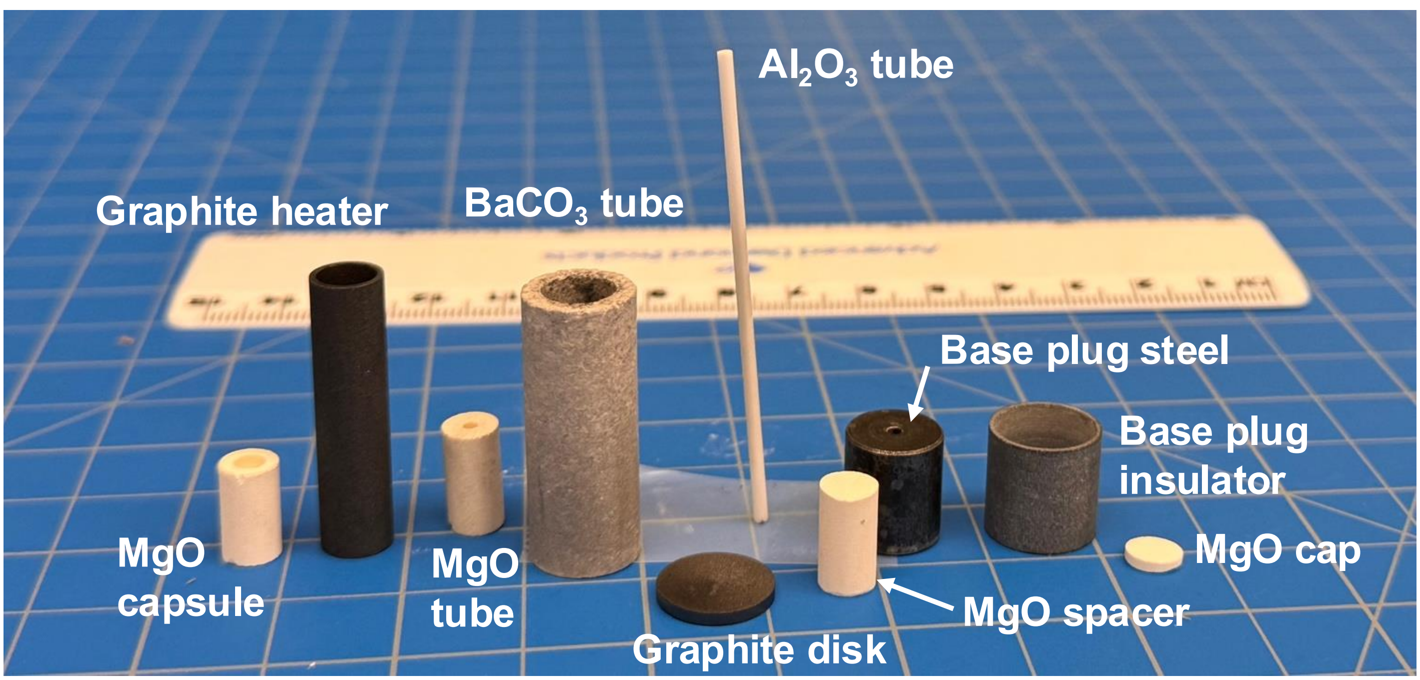
1.2.2 What to do:

- Note: This should be done once you are ready to build the stack and run the experiment.
- Connect the DATAQ acquisition kit to the computer.
- Open DATAQ Software on the computer. When the manager window opens, click Open Windaq.
- Click Edit → Enable Channels and ensure the top-most left corner label (corresponding to channel 1) is set to V.
- Click Edit → Chanel Settings and on the Channel 1 tab ensure the input type is set to 100 gain, ranging from -0.5 to 0.5. Troubleshoot: if these numbers don't show up on the screen, change the source on the right-hand side from voltage to thermocouple and then back to voltage to reset it.
- Hold the end of the thermocouple in your hand and watch for a change in the voltage reading. Troubleshoot: if the change is negative, try resetting it. If there is no change, there's a chance the wires are not touching at the tip of the thermocouple, or they are mistakenly touching somewhere else.
- Optionally, under Edit → Enable Channels, double click the fourth channel label and click the "T" key to set the fourth channel to temperature. Channels 2 and 3 are not connected to the thermocouple so disregard them. Then under Edit → Chanel Settings, click next 3 times to the Channel 4 tab and ensure it is reading Type J. We are using Type C, but that is not an option. Using voltage on Channel 1 eliminates this problem, but if you want to see a very approximate temperature reading, you can use Channel 4 for this.

1. Preparing the Cell Assembly

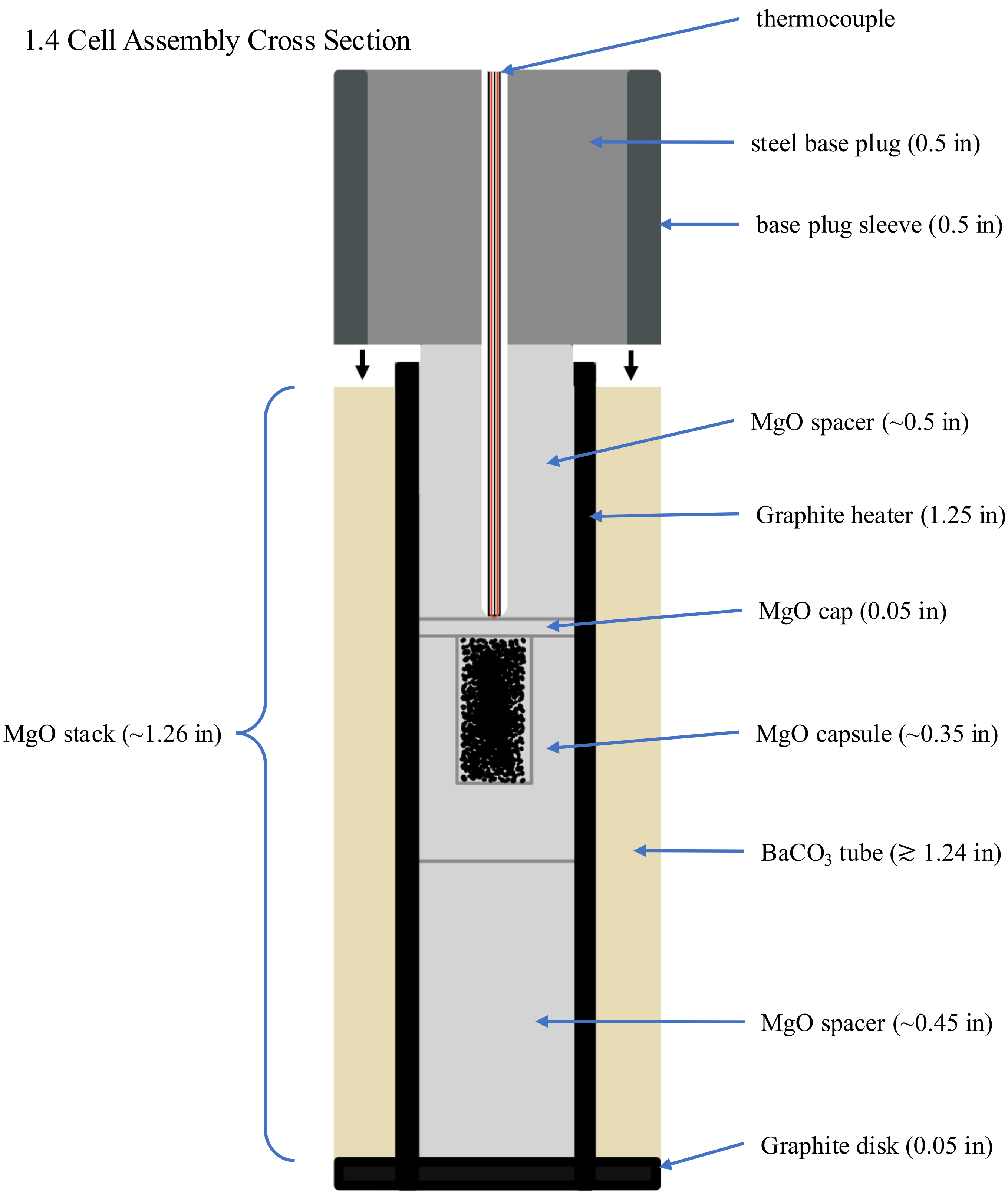
1.3 Cell Assembly Parts





1. Preparing the Cell Assembly

1.4 Cell Assembly Cross Section



1. Preparing the Cell Assembly

1.5 Building the Cell

1.5.1 What you need:

- MgO solid cylinder
- MgO hollow cylinder
- X-Acto saw, caliper, sandpaper (150 grit), Milwaukee drill, 1/8th in DeWalt drill bit, clamp
- Sample powder, weigh paper, spatula

1.5.2 What to do:

- Using the caliper and the X-Acto saw, measure and cut the solid MgO cylinder into a 0.05 in section and a 0.45 in section. Note: it's best to cut a section slightly longer than you need and then sand it down to ensure you get exactly the right length.
- Measure and cut a 0.5 in section from the hollow MgO cylinder using the same technique.
- Clamp the remaining piece of solid MgO, which will be used for the capsule. Using the caliper, measure 0.15–0.2 in (depending on how much sample you want for the experiment) on the drill bit and mark the length with tape.
- Drill into the MgO until the tape reaches the surface. The drill tends to pull up and right, so be sure to hold it steady and potentially start a little off center to account for this. It may take a few tries with the drill—this is ok! If your first attempt (or second, or third) is off center or too shallow/deep, you can simply cut or sand the surface and try again.
- After you have a capsule that is centered and 0.15–0.2 in deep, you can measure and cut the MgO cylinder to be ~0.35 in (the 0.15–0.2 in deep hole plus the $\geq$ 0.15 in solid base).
- Sand the ends of each piece of MgO after cutting to make sure they are flat.
- Note: none of these sections need to be exactly these lengths, as long as the are close. In general, the cap piece should not be thinner than 0.05 in, and the capsule piece should be thick enough to have a solid base at least 3x as thick as the cap (0.15 in) below the hole. The total MgO stack should be $\gtrsim$ the height of the Graphite cylinder (1.25 in). Making it slightly taller (~1.26 in) helps keep the thermocouple from breaking.
- To load the cell, place a piece of weigh paper beneath the 0.35 in MgO capsule. Clean a spatula and scoop the sample powder onto a piece of creased weigh paper. Carefully tip the powder into the hole in the MgO capsule.

1. Preparing the Cell Assembly

1.5 Building the Cell cont.

1.5.1 What you need:

- ≳1.24 in $BaCO_3$ hollow tube (HANDLE WITH GLOVES; DO NOT EAT)
- ~1.25 in Graphite hollow tube
- 1.25–1.26 in MgO stack (solid spacer, capsule, cap, hollow thermocouple spacer)
- 0.05 in Graphite disk
- ~1.25 in x ~2 in lead foil (HANDLE WITH GLOVES; DO NOT EAT)

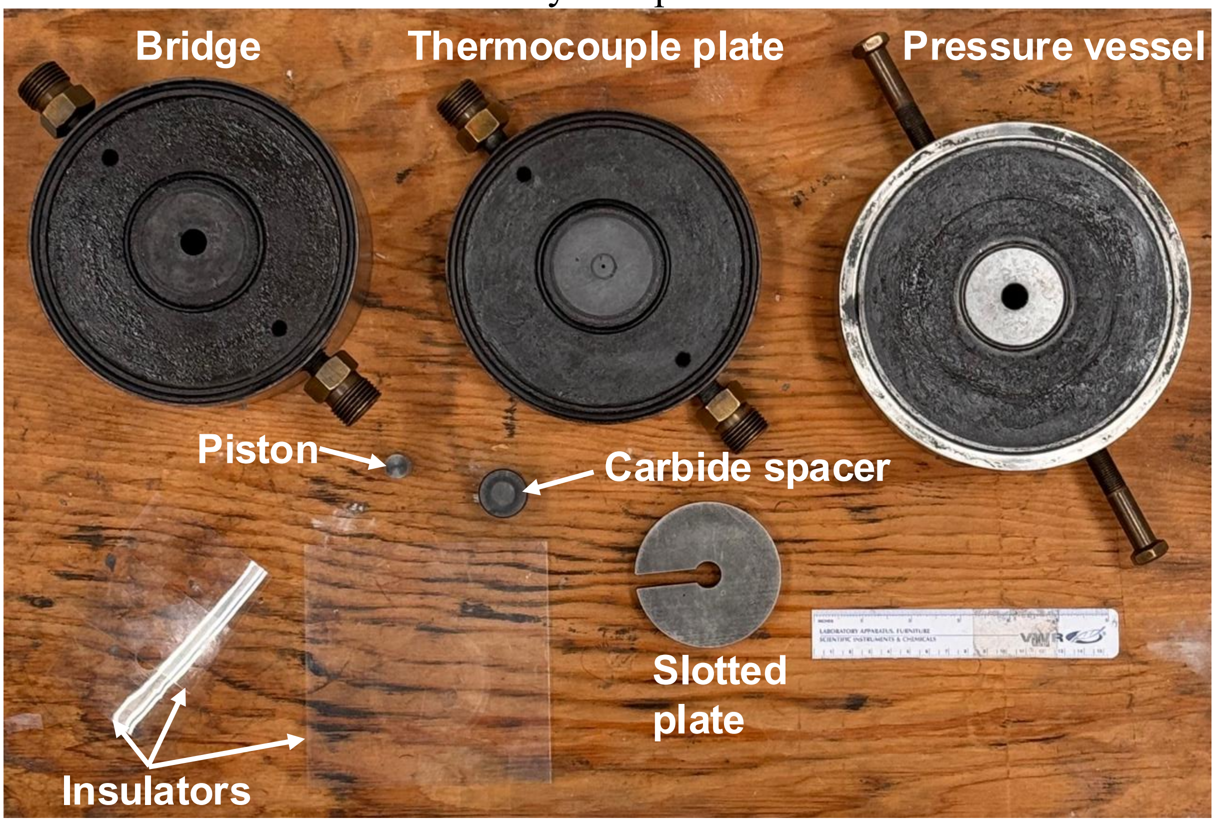
1.5.2 What to do:

- Select a $BaCO_3$ cylinder that is ≳1.24 in. Insert the 1.25 in Graphite cylinder into the $BaCO_3$. Be careful, the $BaCO_3$ is very delicate and can break easily! Note: if only broken $BaCO_3$ is available, it's ok to still use it as long as the cracks line up perfectly/no material is missing.
- Insert the MgO stack into the Graphite cylinder in the following order: first the 0.45 in solid MgO spacer, then the loaded 0.35 in MgO capsule, then the 0.05 in MgO cap, and finally the 0.5 in hollow MgO thermocouple spacer.
- Note: be sure to hold the cell assembly together upright and carefully once all the pieces have been inserted. Some MgO pieces will slide easier in the Graphite cylinder than others, and it's possible for the MgO stack to fall out if not handled with care!
- Cut a ~1.25 in x ~2 in lead foil rectangle. It should be wide enough to wrap around the cell assembly 1–2 times, and long enough that it can cover most of the length of the $BaCO_3$ tube and have enough remaining foil at the end to fold in and fully cover the bottom of the assembly.
- When folding the lead, the top 20% of the $BaCO_3$ should be left exposed. (If the lead reaches the top of the $BaCO_3$, it can cause the heater to short circuit.) Make sure the bottom foil is tucked in neatly and not sticking out any wider than the width of the assembly.
- Note: any excess lead or broken $BaCO_3$ needs to be disposed of in the hazardous waste bin!

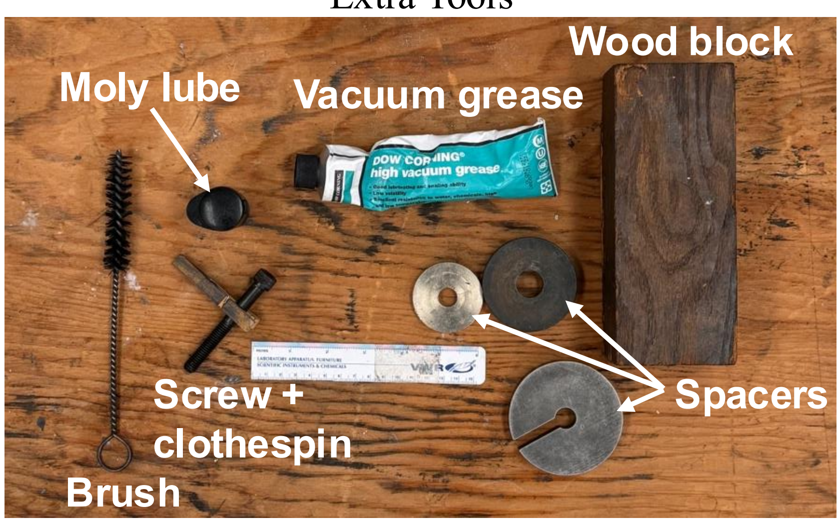
2. Building the Stack

2.1 Piston Cylinder Parts

Primary Components



Extra Tools

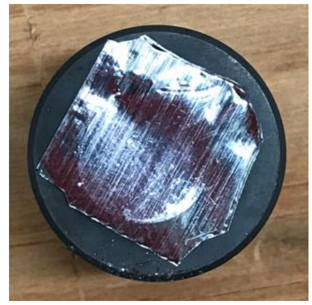


2. Building the Stack

2.1 Piston Cylinder Parts cont.


Main hydraulic ram


Carbide spacer


Lead shim


Bridge


Piston

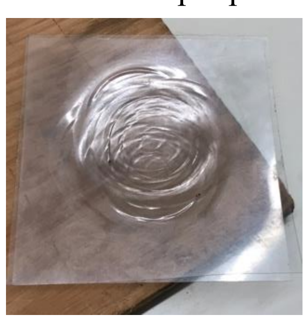

Pressure vessel


Thermocouple insulator


Thermocouple plate


Slotted plate

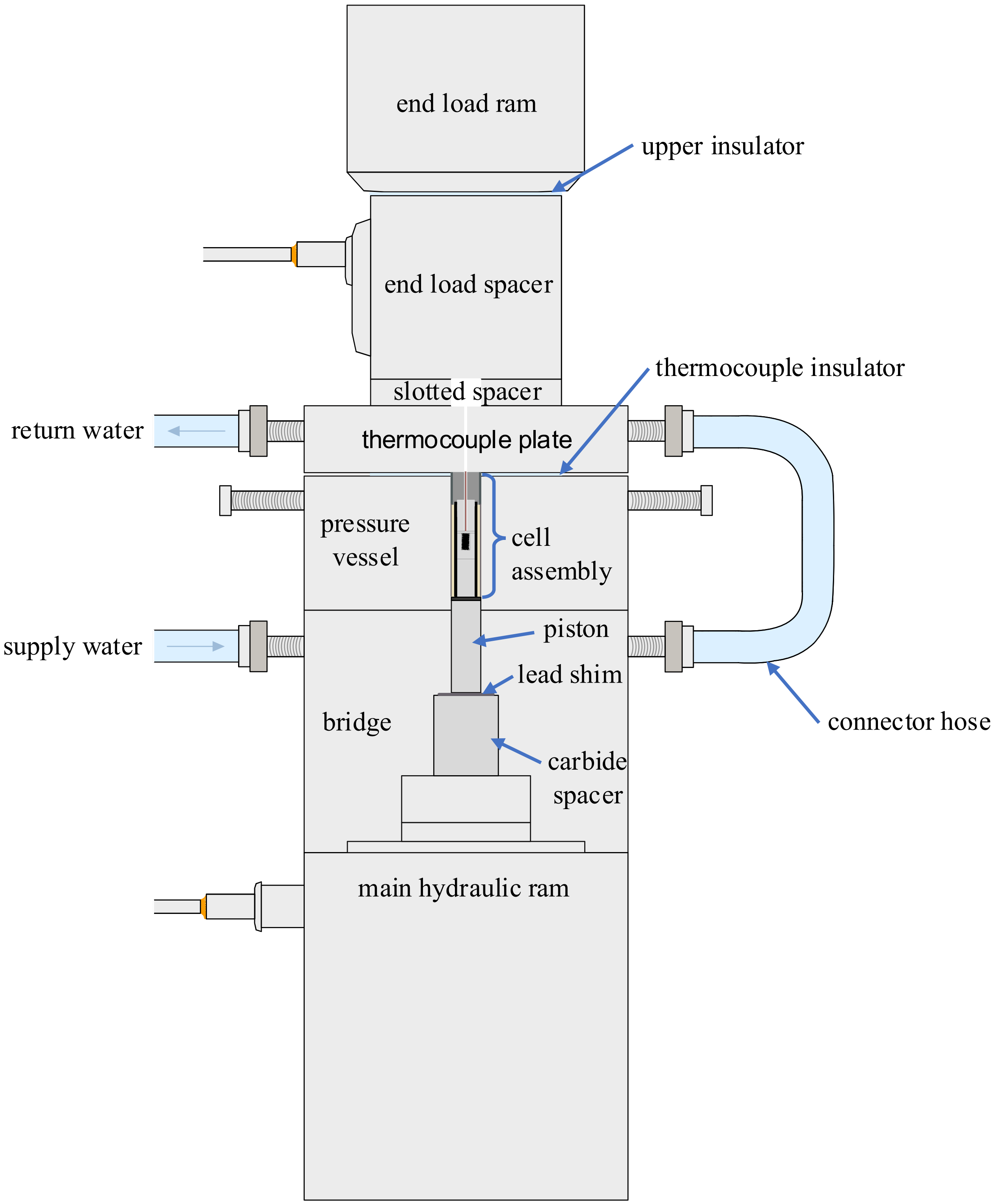

End load spacer


Upper insulator


End load ram

2. Building the Stack

2.2 Piston Cylinder Cross Section



2. Building the Stack

2.3 Assembly

2.3.1 What you need:

- All PC parts (carbide spacer, piston, bridge, pressure vessel, thermocouple plate, slotted spacer)
- Completed Cell Assembly, 0.05 in Graphite disk, steel base plug, insulator sleeve, completed thermocouple
- Moly-lube and vacuum grease
- Lead shim, 2 Mylar sheets, 2 Mylar sheets with holes in the center
- .61 pin gauge, screw

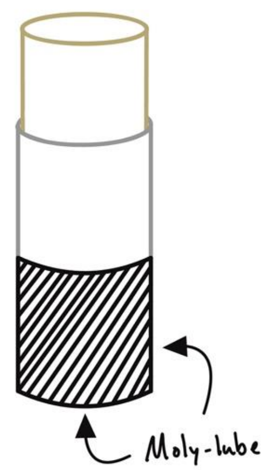
2.3.2 What to do:

- Check if the surfaces of the bridge, pressure vessel, and thermocouple plate are clean. There should be no visible dirt or fragments on the surfaces, and each should have a very thin, even layer of grease. The rubber O-rings should also be greased.
- If there is dirt or not enough grease, place 1–2 penny-sized dallops of vacuum grease (from the white and green toothpaste-type container) on each surface. Wipe evenly using a kimwipe. For greasing O–rings, place a dallop on a kimwipe and rub around the O-ring. The layers of grease should be uniform and very thin! (You shouldn't have to grease every time, O-rings need to be greased roughly once every 6 months, and the surfaces should be greased roughly once every 6 months or whenever dirty—whichever comes first.)
- Cut a circle out of the lead foil that is smaller than the carbide spacer but larger than the piston (between 0.5–0.9 in diameter).
- Place the carbide spacer in the center of the main hydraulic ram. Place the lead shim on top of the carbide spacer. Place the bridge on top of the main hydraulic ram, being careful to center it over the carbide spacer. It should rest flat, so if there is any wobble it's not set properly. Arrange it so the hose port is facing straight ahead.
- Insert the piston into the hole in the bridge. When it rests on the lead shim, the top should stick out 3-5 mm above the bridge. If it does not, you may need to readjust the height of the main hydraulic ram (see page 24).

2. Building the Stack cont.

2.3.2 What to do:

- Place the pressure vessel on top of the piston, making sure it locks into place. To make sure it is right side up, the handles should be near the top surface, not the bottom. Insert the 0.05 in Graphite disk into the pressure vessel core. Use the screw to push the graphite disk down until it is sitting flat on top of the piston. (Don't push too forcefully at the bottom, or the disk may break. You should be able to easily tell when it reaches the piston. Make sure it lies flat!)



- Coat the base and the bottom half of the sides of the lead-covered cell assembly in an extremely thin layer of moly-lube. Open the black film canister and dab a bit on your gloved finger. Spread this around the bottom half of the cell assembly and its base until you get as thin and even a layer as possible.
- Insert the cell assembly into the pressure vessel core. Gently push the $BaCO_3$ outer ring (*not* the MgO stack) to push the assembly all the way into the core. This is a tight fit, but it shouldn't require too much force—try twisting it if it gets stuck. If you're still having trouble, you may need to wrap the lead foil tighter around the cell.
- Put the steel base plug into the insulator sleeve and insert both into the pressure vessel core. The top should be level with or $\lesssim$1 mm higher than the pressure vessel surface.
- Place 2 Mylar sheets with holes in the center onto the top of the pressure vessel, aligning the holes with the steel base plug and sleeve. If the plug and sleeve stick up slightly above the pressure vessel, they will hold the Mylar sheets in place. If instead they are level with the surface, you just need to be very careful to avoid moving the Mylar sheets in the next step.
- Lift up the thermocouple plate. While holding it, have a second person stick the 0.61 pin gauge into the hole in the plate until you can see it sticking out underneath. Don't drop it! Lower the thermocouple plate onto the pressure vessel, and—using the pin sticking out the bottom—align the hole in the plate with the hole in the steel base plug. Lower the pin as far as you can without dropping it to make sure the holes are totally aligned. This may take a few tries. Make sure the hose port is facing straight ahead and in line with the port on the bridge.
- Test the thermocouple using the DATAQ software (see page 5).

2. Building the Stack cont.

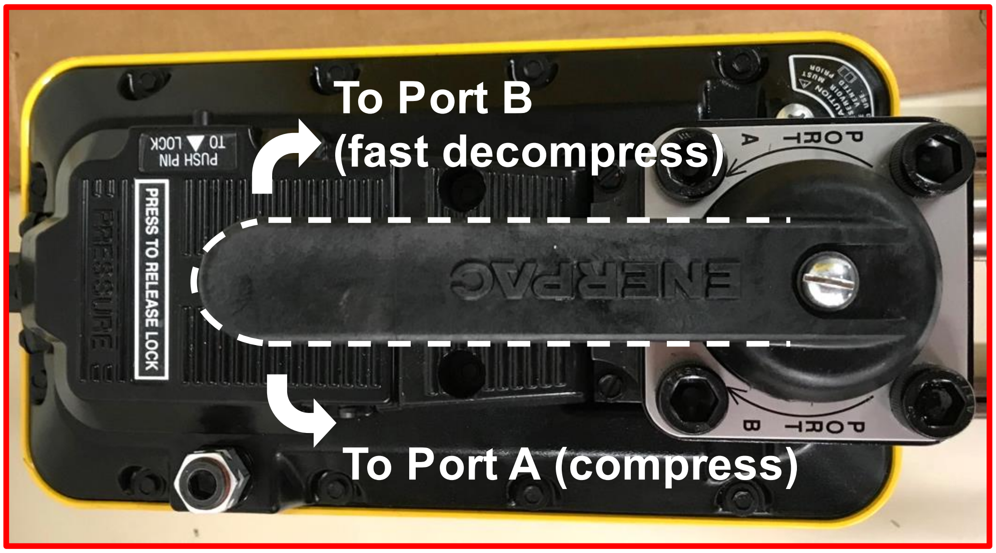
2.3.2 What to do:

- Remove the pin and insert the completed thermocouple into the hole in the thermocouple plate. It should be able to be pushed through the thermocouple plate, steel base plug, and hollow MgO spacer, and end up against the MgO cap. Only a few mm of thermocouple should be left exposed. If much more is exposed (and your thermocouple is the right length), the holes may not be perfectly aligned, preventing the thermocouple from going all the way in. You may need to readjust the thermocouple plate with the pin gauge to correct the alignment.
- Make sure the wires exiting the thermocouple do not touch each other where exposed. Add the slotted spacer on top of the thermocouple plate, aligning the hole and the slot with the thermocouple and the exiting wires, respectively.
- Place the end load spacer on top of the slotted plate. Place 2 Mylar sheets between the end load spacer and the end load ram. Make sure the slotted spacer does not move and damage the wires during this process. Make sure the end load spacer is lined up with the end load ram. This may require you to hold the spacer in place until pressure is applied.

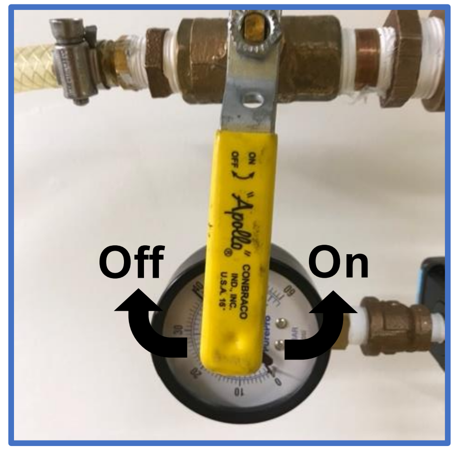
3. Running the Experiment

3.1 Pressure Control Parts

Turbo II Air Pump



Air Valve

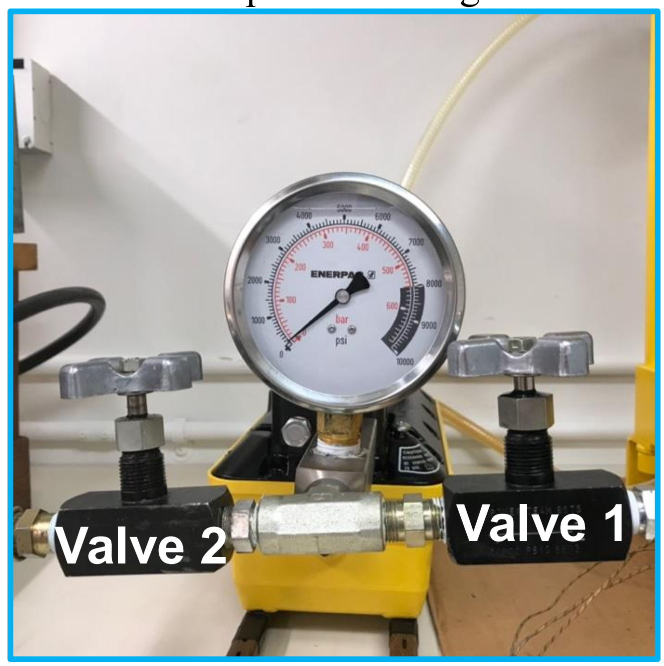


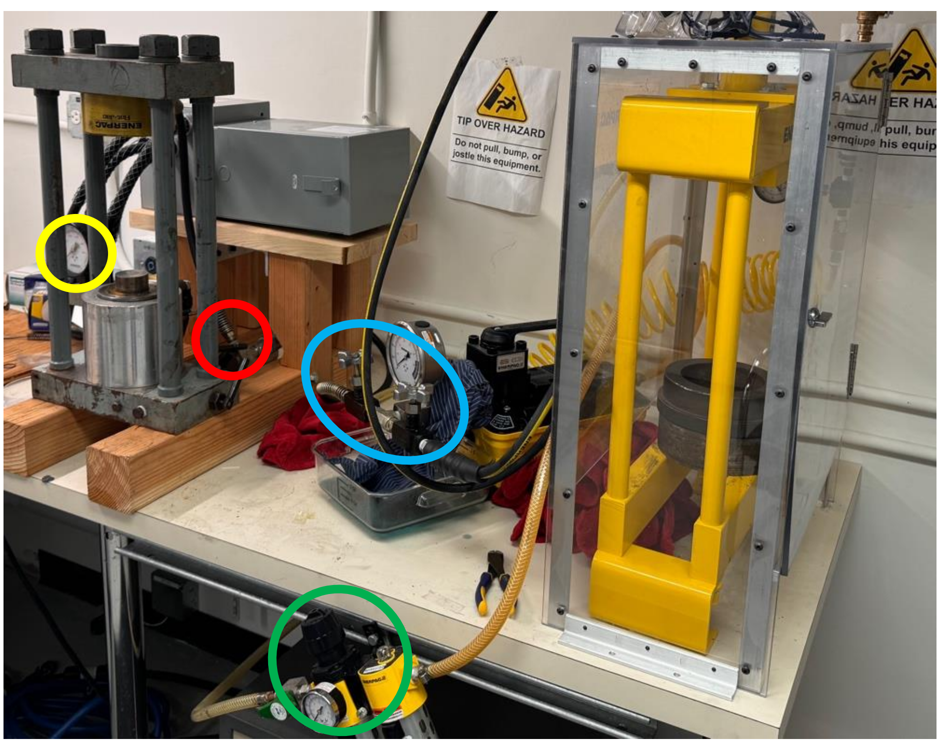
3. Running the Experiment

3.1 Pressure Control Parts cont.

Press Valve/Gauge

Pump Valves/Gauge





Regulator Dial

3. Running the Experiment

3.2 Compression

3.2.1 What you need:

- Air Valve, Turbo II Air Pump, Valve 2, Valve 3, Regulator Dial

3.2.2 What to do:

- Close Valve 1 (to the right of the pump when facing the pump and the wall) and Valve 3 (the valve behind the press). Open Valve 2 (to the left of the pump when facing the pump and wall) all the way. Note that you need to turn the dials a lot to get them all the way open/closed. Turn the pump to Port A (rotate the lever in a counterclockwise direction). Make sure the regulator dial (the black cap above the green lever) is unlocked (turned counterclockwise).
- Turn on the Air Valve. Always open the air valve slowly and carefully! There will be loud banging—this is normal. Let the pressure in the gauge on the pump build to 1,000–2,000 psi.
- Turn off the Air Valve and open Valve 3. The pressure in the press gauge should drop and the pressure in the pump gauge should rise. They should quickly equilibrate. Check to make sure the upper insulator is now firmly sealed against the end load ram and spacer.
- Quickly turn on the Air Valve again to maintain pressure—it will fall while the Air Valve is turned off. Open the Air Valve enough to allow the pressure to slowly rise to 7,000 psi (equivalent to 1 GPa). Lock the regulator as the pressure reaches 7,000 psi to keep the target pressure during the experiment. Leave the Air Valve open and expect occasional bangs as the pressure is kept constant.

3. Running the Experiment

3.3 Temperature Control Parts

EUROTHERM Heater

EUROTHERM Control Panel

Supply and Return Hoses

Connector Hose

3. Running the Experiment

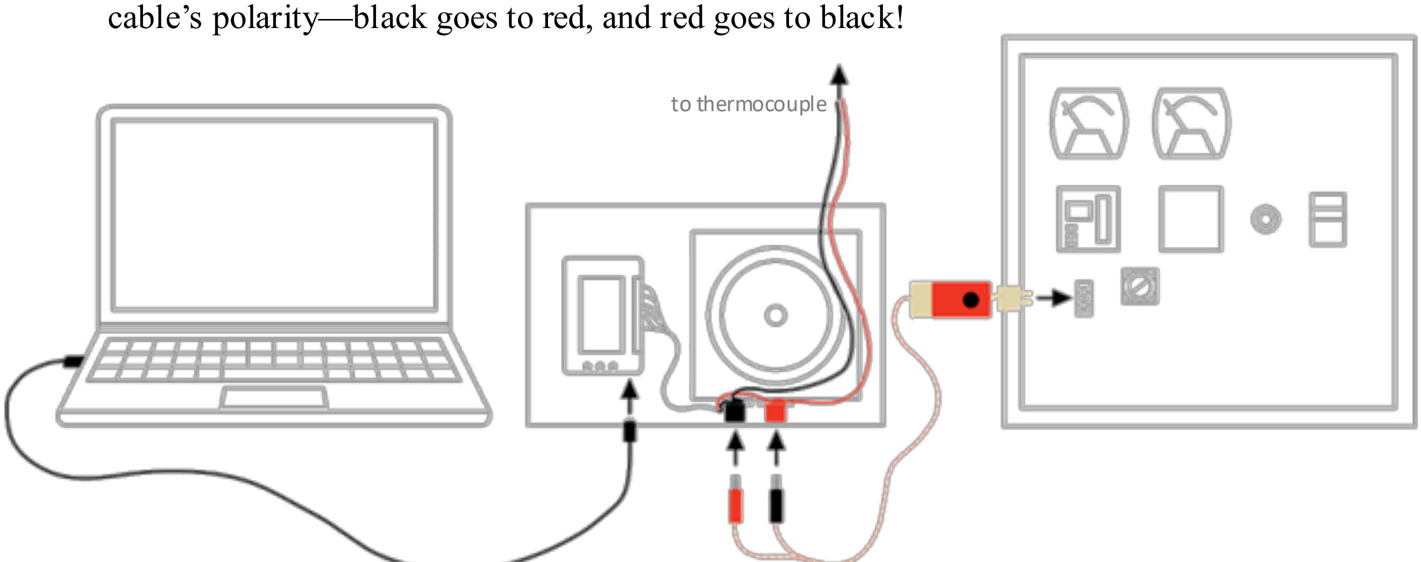
3.4 Heating

3.4.1 What you need:

- Supply Hose, Return Hose, Connector Hose
- EUROTHERM Heater
- Computer, DATAQ acquisition kit, thermocouple

3.4.2 What to do:

- Once the sample is under compression, connect the short hose in the back to the thermocouple plate and the bridge. If the connection is weak, you can tighten the screws near the ends of the hose. You can also add vacuum grease to the hose threads.
- Connect the return water to the thermocouple hose port and then the supply water to the bridge port. Open the return and supply valves. Check to ensure the water is sealed well. Some small leaks near the hose ports are ok, but there should not be water leaking out between the layers of the stack. If there is, you cannot continue the experiment. Troubleshoot: try regreasing the plate surfaces and replacing the O-rings.
- Plug the heater cable into the socket behind the press. Push the throw switch on the right of the heater to ON. On the reading display, click the first of the three buttons that says SET to switch to setting mode. Set the target to 0 mV using the black dial (spinning left decreases, spinning right increases). Then switch the knob below the reading display to TEMP (ON).
- Plug the DATAQ acquisition kit into the computer. Connect the thermocouple cable to the heater and the DATAQ acquisition kit. Note: at the DATAQ acquisition kit, reverse the cable's polarity—black goes to red, and red goes to black!



3. Running the Experiment

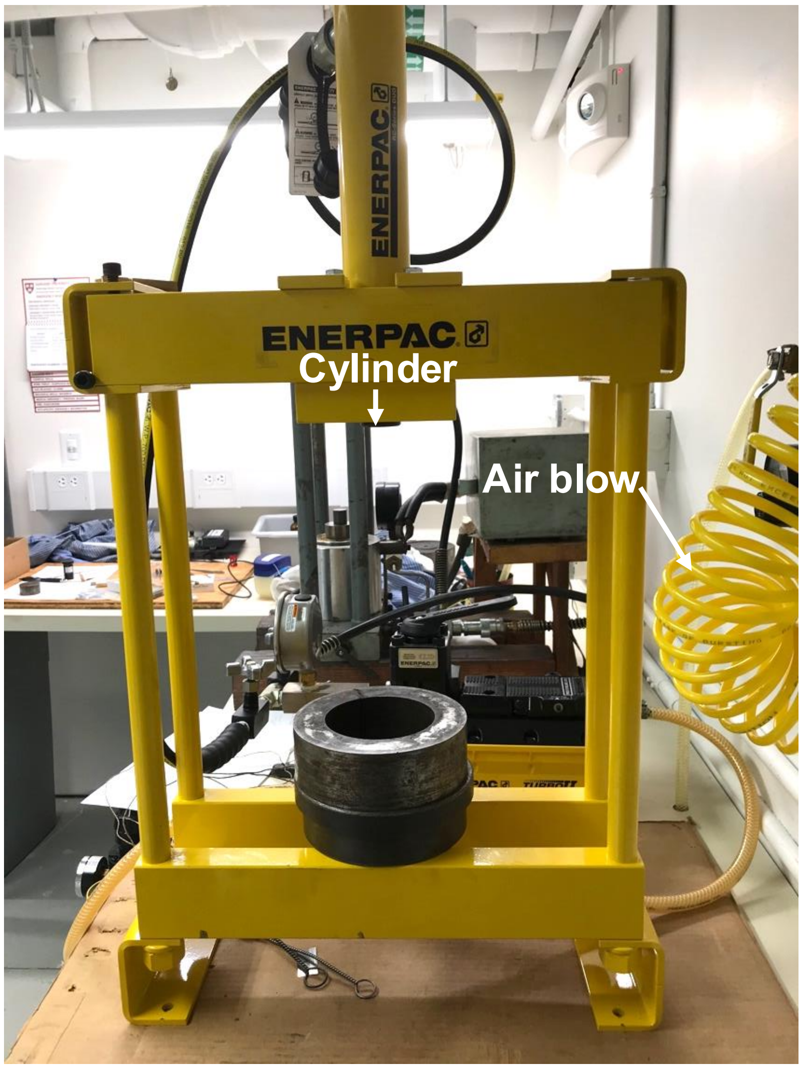
3.4 Heating cont.

3.4.2 What to do:

- Open the DATAQ software and setup the program (see page 5: Testing the Thermocouple). Then click Edit → Sample Rate to change the sample to 50. (This decreases oscillations in the temperature reading.)
- Click File → Open and create a name for a new experiment file. Click Open, add a 0 to the file size, and click Okay. Click File → Record to begin recording in the file.
- Use the dial to enter 3–4 mV. Push the middle button on the reading display that says M.V. to confirm the target temperature and enter the heating mode. Note: it takes several minutes after clicking the button for heating to actually begin. Be patient! You will hear a buzz when it starts, and then the number on the reading display screen will begin to rise.
- Note: the frame is now an electric shock hazard! DO NOT TOUCH THE PRESS.
- Once heating begins, the voltage should increase on the heater display and on the data acquisition software on the computer. It's important to watch both. Let the heater stay at 3–4 mV for a few minutes before increasing the target temperature again. Note: once the heater reaches its target, it will increase a bit past that point before stopping.
- When ready, increase the target temperature again by clicking the SET button and turning the dial to the desired voltage. Click the m.V. button and wait. Take at least one more intermediate increasing step before going all the way to the final target T.
- To identify the final target temperature, use the attached Thermocouple Reference table for temperature versus voltage conversion (see page 26). (1600℃ = 28.2 mV; 1700℃ = 29.7 mV; 1800℃ = 31.1 mV.) Keep your sample above your target temperature for $\gtrsim$ 1 minute.
- Note: Throughout heating, the DATAQ software may show long-period oscillations. These are normal, but we aren't sure what causes them. Just make sure that the target temperature is in the middle of the fluctuations.
- Note: the heater may become unstable at high temperatures. If the temperature starts to run away uncontrollably, you can switch the knob below the reading display to OFF to exit the heating mode quickly. It is important not to let the temperature get too high, because it may melt the thermocouple.
- Note: as the target is increased, the VOLTS meter will increase. The AMPERES meter will not increase until higher temperatures but should eventually begin to increase as well. If there is never an amp response, something is wrong.
- Note: if the fuse in the power supply blows, there will be no symptoms besides not heating.

4. Finishing the Experiment

4.1 Cleanup Parts



4. Finishing the Experiment

4.1 Decompression

4.1.1 What you need:

- Wood block, 2 0.5 in spacers, 0.25 in spacer
- Air Valve, Turbo II Air Pump, Valve 2, Valve 3
- Air Blow, Bucket

4.1.2 What to do:

- After you have maintained your target T for the desired time, press the SET button in the reading display to exit the heating mode, switch the knob below the display to OFF, and push the throw switch on the right to its OFF position. Finally, unplug the power supply cable. On the computer, click File → Stop to stop the recording.
- Turn off the supply water and then the return water. Disconnect the return water hose and use the air blow to blow into the hose to remove residual water. Water will likely leak out of the port as you disconnect the hose, so have a bucket or rag ready. Before returning the hose, see if you can shake any last water out into the bucket.
- Repeat with the supply hose. After you've returned both hoses to their place, use the air blow on the thermocouple hose port and place the bucket below the bridge port to blow out all the remaining water in the press. Finally, disconnect the connector hose.
- Turn off the Air Valve. Close Valve 2. Switch the pump to the middle position by rotating the lever clockwise (but not all the way to Port B). Slowly crack open Valve 2 less than half a turn. Both gauges should begin to slowly fall.
- If you want to decompress faster, open Valve 2 more, or switch the pump to Port B. Speed does not seem to have a big effect on decompression, but going slowly may help prevent the thermocouple from fully shattering and may be safer in general. If for whatever reason your decompression is quick, it's still ok.
- When the gauges reach 0, the upper insulator should be loose and easily removed. If not, try switching the pump to Port B. Remove the end load spacer and slotted plate. Unscrew the regulator dial.
- Hold the wires taut in one hand and slide the thermocouple plate quickly to the side to shear the thermocouple. Remove the thermocouple plate and the detached wires. Remove the pressure vessel (with the piston, cell assembly, and broken thermocouple still inside), the bridge, and the carbide spacer.

4. Finishing the Experiment

4.1 Decompression cont.

4.1.2 What to do:

- Place the large wood block on top of the main hydraulic ram and then add the three spacers that fit between the wood and the end load ram. There should be a small gap. Switch the pump to Port A and fully open Valve 2 again.
- Open the Air Valve. The main hydraulic ram will briefly advance until the gap at the top of the press is closed. Then, the end load ram will advance and begin to push the main hydraulic ram back down. Turn off the Air Valve when the black line on the main hydraulic ram is flush with the surrounding plate—this is the original position that the ram must be in for the start of the next experiment.
- Switch to Port B to retract the end load ram. Close Valve 2 and Valve 3.

4. Finishing the Experiment

4.2 Sample Recovery

4.2.1 What you need:

- Pressure Vessel, Screw, Clothespin, Dish
- ENERPAC Cylinder, Air Valve, Turbo II Air Pump, Valve 1
- Brush, Vacuum Grease

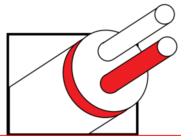
4.2.2 What to do:

- Open Valve 1. Switch the pump to Port A. Valves 2 and 3 should still be closed.
- Take the pressure vessel and balance it inside the hydraulic cylinder apparatus on the metal booster. The side with the piston sticking out should be facing down. Make sure the center of the pressure vessel is roughly centered with the hydraulic cylinder at the top. Arrange a dish below to catch the piston and cell assembly when they fall out.
- Clip the screw using the clothespin and hold it balanced on top of the core.
- Open the air valve and let the cylinder advance. As soon as the screw is held in place by the pressure of the cylinder, let go of the clothespin and shut the plexiglass door.
- As the cylinder pushes the screw down, first the piston and then the cell assembly will drop into the dish.
- Close the Air Valve as soon as the cell assembly falls out and the screw drops. Switch to Port B on the pump to retract the cylinder.
- After the cylinder is fully retracted, close Valve 1 and reset the pump to 0 or Port A to prepare for the next experiment.
- Collect the sample from the dish. Use pliers to carefully break the lead, graphite, and $BaCO_3$. It's best to wear a mask while doing this as the $BaCO_3$ can crumble into a very fine powder. Save all the pieces of MgO that could have sample in them. Save the steel base plug. Throw the rest of the cell assembly away into the hazardous waste bin.
- Clean the piston and the steel base plug using a kimwipe. Use the brush to scrub the cores of the pressure vessel and the bridge. (If there is anything left in the cores, loading the next experiment will be impossible.) Check the surfaces of the bridge, pressure vessel, and thermocouple plate for dirt. Clean them with grease if necessary (see page 13).

MAXIMUM TEMPERATURE RANGE
Thermocouple Grade
-32 to 4208°F
-0 to 2320°C
Extension Grade
32 to 1600°F
0 to 870°C
LIMITS OF ERROR
(whichever is greater)
Standard: 4.5°C to 425°C
1.0% to 2320°C
Special: Not Established
COMMENTS, BARE WIRE ENVIRONMENT:
Vacuum, Inert; Hydrogen; Beware of Embrittlement; Not Practical Below 750°F; Not for Oxidizing Atmosphere
TEMPERATURE IN DEGREES °C
REFERENCE JUNCTION AT 0°C

°C

Tungsten-5% Rhenium vs. Tungsten-26% Rhenium



Extension Grade

Revised Thermocouple Reference Tables

IEC color code

ANSI color code

TYPE C

Reference Tables ANSI/ASTM E-230

Thermoelectric Voltage in Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
0	0.000	0.013	0.027	0.040	0.054	0.067	0.081	0.094	0.108	0.122	0.135	0
10	0.135	0.149	0.163	0.176	0.190	0.204	0.218	0.231	0.245	0.259	0.273	10
20	0.273	0.287	0.301	0.315	0.329	0.342	0.356	0.370	0.385	0.399	0.413	20
30	0.413	0.427	0.441	0.455	0.469	0.483	0.498	0.512	0.526	0.540	0.555	30
40	0.555	0.569	0.583	0.598	0.612	0.627	0.641	0.656	0.670	0.685	0.699	40
50	0.699	0.714	0.728	0.743	0.757	0.772	0.787	0.801	0.816	0.831	0.846	50
60	0.846	0.860	0.875	0.890	0.905	0.920	0.934	0.949	0.964	0.979	0.994	60
70	0.994	1.009	1.024	1.039	1.054	1.069	1.084	1.099	1.114	1.129	1.145	70
80	1.145	1.160	1.175	1.190	1.205	1.221	1.236	1.251	1.266	1.282	1.297	80
90	1.297	1.312	1.328	1.343	1.359	1.374	1.389	1.405	1.420	1.436	1.451	90
100	1.451	1.467	1.483	1.498	1.514	1.529	1.545	1.561	1.576	1.592	1.608	100
110	1.608	1.624	1.639	1.655	1.671	1.687	1.702	1.718	1.734	1.750	1.766	110
120	1.766	1.782	1.798	1.814	1.830	1.846	1.862	1.878	1.894	1.910	1.926	120
130	1.926	1.942	1.958	1.974	1.990	2.006	2.023	2.039	2.055	2.071	2.087	130
140	2.087	2.104	2.120	2.136	2.152	2.169	2.185	2.201	2.218	2.234	2.251	140
150	2.251	2.267	2.283	2.300	2.316	2.333	2.349	2.366	2.382	2.399	2.415	150
160	2.415	2.432	2.449	2.465	2.482	2.498	2.515	2.532	2.548	2.565	2.582	160
170	2.582	2.599	2.615	2.632	2.649	2.666	2.682	2.699	2.716	2.733	2.750	170
180	2.750	2.767	2.784	2.800	2.817	2.834	2.851	2.868	2.885	2.902	2.919	180
190	2.919	2.936	2.953	2.970	2.987	3.004	3.021	3.039	3.056	3.073	3.090	190
200	3.090	3.107	3.124	3.141	3.159	3.176	3.193	3.210	3.228	3.245	3.262	200
210	3.262	3.279	3.297	3.314	3.331	3.349	3.366	3.383	3.401	3.418	3.436	210
220	3.436	3.453	3.470	3.488	3.505	3.523	3.540	3.558	3.575	3.593	3.610	220
230	3.610	3.628	3.645	3.663	3.680	3.698	3.716	3.733	3.751	3.768	3.786	230
240	3.786	3.804	3.821	3.839	3.857	3.875	3.892	3.910	3.928	3.945	3.963	240
250	3.963	3.981	3.999	4.017	4.034	4.052	4.070	4.088	4.106	4.124	4.141	250
260	4.141	4.159	4.177	4.195	4.213	4.231	4.249	4.267	4.285	4.303	4.321	260
270	4.321	4.339	4.357	4.375	4.393	4.411	4.429	4.447	4.465	4.483	4.501	270
280	4.501	4.519	4.537	4.555	4.573	4.592	4.610	4.628	4.646	4.664	4.682	280
290	4.682	4.701	4.719	4.737	4.755	4.773	4.792	4.810	4.828	4.846	4.865	290
300	4.865	4.883	4.901	4.920	4.938	4.956	4.974	4.993	5.011	5.030	5.048	300
310	5.048	5.066	5.085	5.103	5.121	5.140	5.158	5.177	5.195	5.214	5.232	310
320	5.232	5.250	5.269	5.287	5.306	5.324	5.343	5.361	5.380	5.398	5.417	320
330	5.417	5.435	5.454	5.473	5.491	5.510	5.528	5.547	5.565	5.584	5.603	330
340	5.603	5.621	5.640	5.658	5.677	5.696	5.714	5.733	5.752	5.770	5.789	340
350	5.789	5.808	5.827	5.845	5.864	5.883	5.901	5.920	5.939	5.958	5.976	350
360	5.976	5.995	6.014	6.033	6.051	6.070	6.089	6.108	6.127	6.145	6.164	360
370	6.164	6.183	6.202	6.221	6.240	6.259	6.277	6.296	6.315	6.334	6.353	370
380	6.353	6.372	6.391	6.410	6.429	6.447	6.466	6.485	6.504	6.523	6.542	380
390	6.542	6.561	6.580	6.599	6.618	6.637	6.656	6.675	6.694	6.713	6.732	390
400	6.732	6.751	6.770	6.789	6.808	6.827	6.846	6.865	6.884	6.903	6.922	400
410	6.922	6.941	6.961	6.980	6.999	7.018	7.037	7.056	7.075	7.094	7.113	410
420	7.113	7.132	7.152	7.171	7.190	7.209	7.228	7.247	7.267	7.286	7.305	420
430	7.305	7.324	7.343	7.362	7.382	7.401	7.420	7.439	7.458	7.478	7.497	430
440	7.497	7.516	7.535	7.554	7.574	7.593	7.612	7.631	7.651	7.670	7.689	440
450	7.689	7.708	7.728	7.747	7.766	7.786	7.805	7.824	7.843	7.863	7.882	450
460	7.882	7.901	7.921	7.940	7.959	7.979	7.998	8.017	8.037	8.056	8.075	460
470	8.075	8.095	8.114	8.133	8.153	8.172	8.191	8.211	8.230	8.249	8.269	470
480	8.269	8.288	8.308	8.327	8.346	8.366	8.385	8.404	8.424	8.443	8.463	480
490	8.463	8.482	8.502	8.521	8.540	8.560	8.579	8.599	8.618	8.637	8.657	490
°C	0	1	2	3	4	5	6	7	8	9	10	°C

°C	0	1	2	3	4	5	6	7	8	9	10	°C
500	8.657	8.676	8.696	8.715	8.735	8.754	8.774	8.793	8.812	8.832	8.851	500
510	8.851	8.871	8.890	8.910	8.929	8.949	8.968	8.988	9.007	9.027	9.046	510
520	9.046	9.066	9.085	9.105	9.124	9.144	9.163	9.183	9.202	9.222	9.241	520
530	9.241	9.261	9.280	9.300	9.319	9.339	9.358	9.378	9.397	9.417	9.436	530
540	9.436	9.456	9.475	9.495	9.514	9.534	9.553	9.573	9.592	9.612	9.631	540
550	9.631	9.651	9.670	9.690	9.710	9.729	9.749	9.768	9.788	9.807	9.827	550
560	9.827	9.846	9.866	9.885	9.905	9.925	9.944	9.964	9.983	10.003	10.022	560
570	10.022	10.042	10.061	10.081	10.100	10.120	10.140	10.159	10.179	10.198	10.218	570
580	10.218	10.237	10.257	10.276	10.296	10.316	10.335	10.355	10.374	10.394	10.413	580
590	10.413	10.433	10.452	10.472	10.491	10.511	10.531	10.550	10.570	10.589	10.609	590
600	10.609	10.628	10.648	10.667	10.687	10.706	10.726	10.746	10.765	10.785	10.804	600
610	10.804	10.824	10.843	10.863	10.882	10.902	10.921	10.941	10.960	10.980	10.999	610
620	10.999	11.019	11.038	11.058	11.077	11.097	11.117	11.136	11.156	11.175	11.195	620
630	11.195	11.214	11.234	11.253	11.273	11.292	11.312	11.331	11.351	11.370	11.390	630
640	11.390	11.409	11.429	11.448	11.468	11.487	11.507	11.526	11.546	11.565	11.585	640
650	11.585	11.604	11.624	11.643	11.663	11.682	11.702	11.721	11.741	11.760	11.780	650
660	11.780	11.799	11.818	11.838	11.857	11.877	11.896	11.916	11.935	11.955	11.974	660
670	11.974	11.994	12.013	12.033	12.052	12.072	12.091	12.111	12.130	12.150	12.169	670
680	12.169	12.189	12.208	12.228	12.247	12.267	12.286	12.306	12.325	12.344	12.364	680
690	12.364	12.383	12.403	12.422	12.442	12.461	12.481	12.500	12.520	12.539	12.559	690
700	12.559	12.578	12.597	12.617	12.636	12.656	12.675	12.695	12.714	12.734	12.753	700
710	12.753	12.772	12.792	12.811	12.831	12.850	12.870	12.889	12.908	12.928	12.947	710
720	12.947	12.967	12.986	13.006	13.025	13.044	13.064	13.083	13.103	13.122	13.141	720
730	13.141	13.161	13.180	13.200	13.219	13.238	13.258	13.277	13.297	13.316	13.335	730
740	13.335	13.355	13.374	13.393	13.413	13.432	13.452	13.471	13.490	13.510	13.529	740
750	13.529	13.548	13.568	13.587	13.606	13.626	13.645	13.665	13.684	13.703	13.723	750
760	13.723	13.742	13.761	13.781	13.800	13.819	13.839	13.858	13.877	13.896	13.916	760
770	13.916	13.935	13.954	13.974	13.993	14.012	14.032	14.051	14.070	14.089	14.109	770
780	14.109	14.128	14.147	14.167	14.186	14.205	14.224	14.244	14.263	14.282	14.301	780
790	14.301	14.321	14.340	14.359	14.378	14.398	14.417	14.436	14.455	14.475	14.494	790
800	14.494	14.513	14.532	14.551	14.571	14.590	14.609	14.628	14.647	14.667	14.686	800
810	14.686	14.705	14.724	14.743	14.763	14.782	14.801	14.820	14.839	14.858	14.878	810
820	14.878	14.897	14.916	14.935	14.954	14.973	14.993	15.012	15.031	15.050	15.069	820
830	15.069	15.088	15.107	15.126	15.146	15.165	15.184	15.203	15.222	15.241	15.260	830
840	15.260	15.279	15.298	15.317	15.336	15.356	15.375	15.394	15.413	15.432	15.451	840
850	15.451	15.470	15.489	15.508	15.527	15.546	15.565	15.584	15.603	15.622	15.641	850
860	15.641	15.660	15.679	15.698	15.717	15.736	15.755	15.774	15.793	15.812	15.831	860
870	15.831	15.850	15.869	15.888	15.907	15.926	15.945	15.964	15.983	16.002	16.021	870
880	16.021	16.040	16.058	16.077	16.096	16.115	16.134	16.153	16.172	16.191	16.210	880
890	16.210	16.229	16.248	16.266	16.285	16.304	16.323	16.342	16.361	16.380	16.398	890
900	16.398	16.417	16.436	16.455	16.474	16.493	16.511	16.530	16.549	16.568	16.587	900
910	16.587	16.606	16.624	16.643	16.662	16.681	16.699	16.718	16.737	16.756	16.775	910
920	16.775	16.793	16.812	16.831	16.850	16.868	16.887	16.906	16.924	16.943	16.962	920
930	16.962	16.981	16.999	17.018	17.037	17.055	17.074	17.093	17.111	17.130	17.149	930
940	17.149	17.167	17.186	17.205	17.223	17.242	17.261	17.279	17.298	17.317	17.335	940
950	17.335	17.354	17.373	17.391	17.410	17.428	17.447	17.465	17.484	17.503	17.521	950
960	17.521	17.540	17.558	17.577	17.595	17.614	17.633	17.651	17.670	17.688	17.707	960
970	17.707	17.725	17.744	17.762	17.781	17.799	17.818	17.836	17.855	17.873	17.892	970
980	17.892	17.910	17.929	17.947	17.966	17.984	18.002	18.021	18.039	18.058	18.076	980
990	18.076	18.095	18.113	18.131	18.150	18.168	18.187	18.205	18.223	18.242	18.260	990
°C	0	1	2	3	4	5	6	7	8	9	10	°C

TEMP-217

Revised Thermocouple Reference Tables

TYPE C

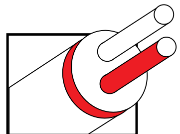
Reference Tables ANSI/ASTM E-230

ANSI color code

IEC color code

°C

Tungsten-5% Rhenium vs. Tungsten-26% Rhenium



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Extension Grade

MAXIMUM TEMPERATURE RANGE

Thermocouple Grade
-32 to 4208°F
-0 to 2320°C

Extension Grade
32 to 1600°F
0 to 870°C

LIMITS OF ERROR
(whichever is greater)
Standard: 4.5°C to 425°C
1.0% to 2320°C
Special: Not Established

COMMENTS, BARE WIRE ENVIRONMENT:
Vacuum, Inert; Hydrogen; Beware of Embrittlement; Not Practical Below 750°F; Not for Oxidizing Atmosphere

TEMPERATURE IN DEGREES °C
REFERENCE JUNCTION AT 0°C

Thermoelectric Voltage in Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
1000	18.260	18.279	18.297	18.315	18.334	18.352	18.370	18.389	18.407	18.425	18.444	1000
1010	18.444	18.462	18.480	18.499	18.517	18.535	18.553	18.572	18.590	18.608	18.627	1010
1020	18.627	18.645	18.663	18.681	18.700	18.718	18.736	18.754	18.773	18.791	18.809	1020
1030	18.809	18.827	18.845	18.864	18.882	18.900	18.918	18.936	18.955	18.973	18.991	1030
1040	18.991	19.009	19.027	19.045	19.064	19.082	19.100	19.118	19.136	19.154	19.172	1040
1050	19.172	19.190	19.208	19.227	19.245	19.263	19.281	19.299	19.317	19.335	19.353	1050
1060	19.353	19.371	19.389	19.407	19.425	19.443	19.461	19.479	19.497	19.515	19.533	1060
1070	19.533	19.551	19.569	19.587	19.605	19.623	19.641	19.659	19.677	19.695	19.713	1070
1080	19.713	19.731	19.749	19.767	19.785	19.803	19.821	19.839	19.856	19.874	19.892	1080
1090	19.892	19.910	19.928	19.946	19.964	19.982	19.999	20.017	20.035	20.053	20.071	1090
1100	20.071	20.089	20.106	20.124	20.142	20.160	20.178	20.195	20.213	20.231	20.249	1100
1110	20.249	20.267	20.284	20.302	20.320	20.338	20.355	20.373	20.391	20.409	20.426	1110
1120	20.426	20.444	20.462	20.479	20.497	20.515	20.532	20.550	20.568	20.585	20.603	1120
1130	20.603	20.621	20.638	20.656	20.674	20.691	20.709	20.727	20.744	20.762	20.779	1130
1140	20.779	20.797	20.815	20.832	20.850	20.867	20.885	20.902	20.920	20.938	20.955	1140
1150	20.955	20.973	20.990	21.008	21.025	21.043	21.060	21.078	21.095	21.113	21.130	1150
1160	21.130	21.148	21.165	21.183	21.200	21.218	21.235	21.253	21.270	21.287	21.305	1160
1170	21.305	21.322	21.340	21.357	21.375	21.392	21.409	21.427	21.444	21.461	21.479	1170
1180	21.479	21.496	21.514	21.531	21.548	21.566	21.583	21.600	21.618	21.635	21.652	1180
1190	21.652	21.670	21.687	21.704	21.721	21.739	21.756	21.773	21.790	21.808	21.825	1190
1200	21.825	21.842	21.859	21.877	21.894	21.911	21.928	21.946	21.963	21.980	21.997	1200
1210	21.997	22.014	22.032	22.049	22.066	22.083	22.100	22.117	22.135	22.152	22.169	1210
1220	22.169	22.186	22.203	22.220	22.237	22.254	22.271	22.289	22.306	22.323	22.340	1220
1230	22.340	22.357	22.374	22.391	22.408	22.425	22.442	22.459	22.476	22.493	22.510	1230
1240	22.510	22.527	22.544	22.561	22.578	22.595	22.612	22.629	22.646	22.663	22.680	1240
1250	22.680	22.697	22.714	22.731	22.748	22.765	22.782	22.799	22.815	22.832	22.849	1250
1260	22.849	22.866	22.883	22.900	22.917	22.934	22.950	22.967	22.984	23.001	23.018	1260
1270	23.018	23.035	23.052	23.068	23.085	23.102	23.119	23.136	23.152	23.169	23.186	1270
1280	23.186	23.203	23.219	23.236	23.253	23.270	23.286	23.303	23.320	23.337	23.353	1280
1290	23.353	23.370	23.387	23.403	23.420	23.437	23.453	23.470	23.487	23.503	23.520	1290
1300	23.520	23.537	23.553	23.570	23.587	23.603	23.620	23.636	23.653	23.670	23.686	1300
1310	23.686	23.703	23.719	23.736	23.753	23.769	23.786	23.802	23.819	23.835	23.852	1310
1320	23.852	23.868	23.885	23.901	23.918	23.934	23.951	23.967	23.984	24.000	24.017	1320
1330	24.017	24.033	24.050	24.066	24.083	24.099	24.116	24.132	24.148	24.165	24.181	1330
1340	24.181	24.198	24.214	24.230	24.247	24.263	24.280	24.296	24.312	24.329	24.345	1340
1350	24.345	24.361	24.378	24.394	24.410	24.427	24.443	24.459	24.476	24.492	24.508	1350
1360	24.508	24.524	24.541	24.557	24.573	24.590	24.606	24.622	24.638	24.655	24.671	1360
1370	24.671	24.687	24.703	24.719	24.736	24.752	24.768	24.784	24.800	24.817	24.833	1370
1380	24.833	24.849	24.865	24.881	24.897	24.913	24.930	24.946	24.962	24.978	24.994	1380
1390	24.994	25.010	25.026	25.042	25.058	25.075	25.091	25.107	25.123	25.139	25.155	1390
1400	25.155	25.171	25.187	25.203	25.219	25.235	25.251	25.267	25.283	25.299	25.315	1400
1410	25.315	25.331	25.347	25.363	25.379	25.395	25.411	25.427	25.443	25.459	25.475	1410
1420	25.475	25.490	25.506	25.522	25.538	25.554	25.570	25.586	25.602	25.618	25.633	1420
1430	25.633	25.649	25.665	25.681	25.697	25.713	25.729	25.744	25.760	25.776	25.792	1430
1440	25.792	25.808	25.823	25.839	25.855	25.871	25.886	25.902	25.918	25.934	25.949	1440
1450	25.949	25.965	25.981	25.997	26.012	26.028	26.044	26.060	26.075	26.091	26.107	1450
1460	26.107	26.122	26.138	26.154	26.169	26.185	26.201	26.216	26.232	26.248	26.263	1460
1470	26.263	26.279	26.294	26.310	26.326	26.341	26.357	26.372	26.388	26.403	26.419	1470
1480	26.419	26.435	26.450	26.466	26.481	26.497	26.512	26.528	26.543	26.559	26.574	1480
1490	26.574	26.590	26.605	26.621	26.636	26.652	26.667	26.683	26.698	26.714	26.729	1490
°C	0	1	2	3	4	5	6	7	8	9	10	°C

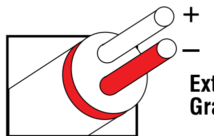
°C	0	1	2	3	4	5	6	7	8	9	10	°C
1500	26.729	26.744	26.760	26.775	26.791	26.806	26.822	26.837	26.852	26.868	26.883	1500
1510	26.883	26.899	26.914	26.929	26.945	26.960	26.975	26.991	27.006	27.021	27.037	1510
1520	27.037	27.052	27.067	27.083	27.098	27.113	27.128	27.144	27.159	27.174	27.190	1520
1530	27.190	27.205	27.220	27.235	27.250	27.266	27.281	27.296	27.311	27.327	27.342	1530
1540	27.342	27.357	27.372	27.387	27.403	27.418	27.433	27.448	27.463	27.478	27.493	1540
1550	27.493	27.509	27.524	27.539	27.554	27.569	27.584	27.599	27.614	27.629	27.645	1550
1560	27.645	27.660	27.675	27.690	27.705	27.720	27.735	27.750	27.765	27.780	27.795	1560
1570	27.795	27.810	27.825	27.840	27.855	27.870	27.885	27.900	27.915	27.930	27.945	1570
1580	27.945	27.960	27.975	27.990	28.005	28.020	28.034	28.049	28.064	28.079	28.094	1580
1590	28.094	28.109	28.124	28.139	28.154	28.169	28.183	28.198	28.213	28.228	28.243	1590
1600	28.243	28.258	28.272	28.287	28.302	28.317	28.332	28.346	28.361	28.376	28.391	1600
1610	28.391	28.406	28.420	28.435	28.450	28.465	28.479	28.494	28.509	28.524	28.538	1610
1620	28.538	28.553	28.568	28.582	28.597	28.612	28.626	28.641	28.656	28.670	28.685	1620
1630	28.685	28.700	28.714	28.729	28.744	28.758	28.773	28.787	28.802	28.817	28.831	1630
1640	28.831	28.846	28.860	28.875	28.890	28.904	28.919	28.933	28.948	28.962	28.977	1640
1650	28.977	28.991	29.006	29.020	29.035	29.049	29.064	29.078	29.093	29.107	29.122	1650
1660	29.122	29.136	29.151	29.165	29.180	29.194	29.209	29.223	29.237	29.252	29.266	1660
1670	29.266	29.281	29.295	29.309	29.324	29.338	29.353	29.367	29.381	29.396	29.410	1670
1680	29.410	29.424	29.439	29.453	29.467	29.482	29.496	29.510	29.525	29.539	29.553	1680
1690	29.553	29.567	29.582	29.596	29.610	29.625	29.639	29.653	29.667	29.681	29.696	1690
1700	29.696	29.710	29.724	29.738	29.753	29.767	29.781	29.795	29.809	29.823	29.838	1700
1710	29.838	29.852	29.866	29.880	29.894	29.908	29.922	29.937	29.951	29.965	29.979	1710
1720	29.979	29.993	30.007	30.021	30.035	30.049	30.063	30.077	30.091	30.106	30.120	1720
1730	30.120	30.134	30.148	30.162	30.176	30.190	30.204	30.218	30.232	30.246	30.260	1730
1740	30.260	30.274	30.288	30.302	30.315	30.329	30.343	30.357	30.371	30.385	30.399	1740
1750	30.399	30.413	30.427	30.441	30.455	30.469	30.482	30.496	30.510	30.524	30.538	1750
1760	30.538	30.552	30.565	30.579	30.593	30.607	30.621	30.635	30.648	30.662	30.676	1760
1770	30.676	30.690	30.704	30.717	30.731	30.745	30.759	30.772	30.786	30.800	30.813	1770
1780	30.813	30.827	30.841	30.855	30.868	30.882	30.896	30.909	30.923	30.937	30.950	1780
1790	30.950	30.964	30.978	30.991	31.005	31.019	31.032	31.046	31.059	31.073	31.087	1790
1800	31.087	31.100	31.114	31.127	31.141	31.154	31.168	31.182	31.195	31.209	31.222	1800
1810	31.222	31.236	31.249	31.263	31.276	31.290	31.303	31.317	31.330	31.344	31.357	1810
1820	31.357	31.371	31.384	31.397	31.411	31.424	31.438	31.451	31.465	31.478	31.491	1820
1830	31.491	31.505	31.518	31.532	31.545	31.558	31.572	31.585	31.598	31.612	31.625	1830
1840	31.625	31.638	31.652	31.665	31.678	31.692	31.705	31.718	31.731	31.745	31.758	1840
1850	31.758	31.771	31.784	31.798	31.811	31.824	31.837	31.851	31.864	31.877	31.890	1850
1860	31.890	31.903	31.917	31.930	31.943	31.956	31.969	31.982	31.996	32.009	32.022	1860
1870	32.022	32.035	32.048	32.061	32.074	32.087	32.101	32.114	32.127	32.140	32.153	1870
1880	32.153	32.166	32.179	32.192	32.205	32.218	32.231	32.244	32.257	32.270	32.283	1880
1890	32.283	32.296	32.309	32.322	32.335	32.348	32.361	32.374	32.387	32.400	32.413	1890
1900	32.413	32.426	32.439	32.451	32.464	32.477	32.490	32.503	32.516	32.529	32.542	1900
1910	32.542	32.554	32.567	32.580	32.593	32.606	32.619	32.631	32.644	32.657	32.670	1910
1920	32.670	32.683	32.695	32.708	32.721	32.734	32.746	32.759	32.772	32.784	32.797	1920
1930	32.797	32.810	32.823	32.835	32.848	32.861	32.873	32.886	32.899	32.911	32.924	1930
1940	32.924	32.937	32.949	32.962	32.974	32.987	33.000	33.012	33.025	33.037	33.050	1940
1950	33.050	33.063	33.075	33.088	33.100	33.113	33.125	33.138	33.150	33.163	33.175	1950
1960	33.175	33.188	33.200	33.213	33.225	33.238	33.250	33.263	33.275	33.287	33.300	1960
1970	33.300	33.312	33.325	33.337	33.350	33.362	33.374	33.387	33.399	33.411	33.424	1970
1980	33.424	33.436	33.448	33.461	33.473	33.485	33.498	33.510	33.522	33.535	33.547	1980
1990	33.547	33.559	33.571	33.584	33.596	33.608	33.620	33.632	33.645	33.657	33.669	1990
°C	0	1	2	3	4	5	6	7	8	9	10	°C

TEMP-218

MAXIMUM TEMPERATURE RANGE
Thermocouple Grade
-32 to 4208°F
-0 to 2320°C
Extension Grade
32 to 1600°F
0 to 870°C
LIMITS OF ERROR
(whichever is greater)
Standard: 4.5°C to 425°C
1.0% to 2320°C
Special: Not Established
COMMENTS, BARE WIRE ENVIRONMENT:
Vacuum, Inert; Hydrogen; Beware of Embrittlement; Not Practical Below 750°F; Not for Oxidizing Atmosphere
TEMPERATURE IN DEGREES °C
REFERENCE JUNCTION AT 0°C

°C

Tungsten-5% Rhenium vs. Tungsten-26% Rhenium



Extension Grade

Revised Thermocouple Reference Tables

IEC color code

ANSI color code

TYPE C

Reference Tables ANSI/ASTM E-230

Thermoelectric Voltage in Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
2000	33.669	33.681	33.693	33.706	33.718	33.730	33.742	33.754	33.766	33.779	33.791	2000
2010	33.791	33.803	33.815	33.827	33.839	33.851	33.863	33.875	33.887	33.899	33.911	2010
2020	33.911	33.923	33.936	33.948	33.960	33.972	33.984	33.996	34.008	34.019	34.031	2020
2030	34.031	34.043	34.055	34.067	34.079	34.091	34.103	34.115	34.127	34.139	34.151	2030
2040	34.151	34.163	34.174	34.186	34.198	34.210	34.222	34.234	34.245	34.257	34.269	2040
2050	34.269	34.281	34.293	34.304	34.316	34.328	34.340	34.351	34.363	34.375	34.387	2050
2060	34.387	34.398	34.410	34.422	34.433	34.445	34.457	34.468	34.480	34.492	34.503	2060
2070	34.503	34.515	34.527	34.538	34.550	34.561	34.573	34.585	34.596	34.608	34.619	2070
2080	34.619	34.631	34.642	34.654	34.665	34.677	34.688	34.700	34.711	34.723	34.734	2080
2090	34.734	34.746	34.757	34.769	34.780	34.792	34.803	34.814	34.826	34.837	34.849	2090
2100	34.849	34.860	34.871	34.883	34.894	34.905	34.917	34.928	34.939	34.951	34.962	2100
2110	34.962	34.973	34.984	34.996	35.007	35.018	35.029	35.041	35.052	35.063	35.074	2110
2120	35.074	35.085	35.097	35.108	35.119	35.130	35.141	35.152	35.164	35.175	35.186	2120
2130	35.186	35.197	35.208	35.219	35.230	35.241	35.252	35.263	35.274	35.285	35.296	2130
2140	35.296	35.307	35.318	35.329	35.340	35.351	35.362	35.373	35.384	35.395	35.406	2140
2150	35.406	35.417	35.428	35.439	35.450	35.461	35.472	35.482	35.493	35.504	35.515	2150
2160	35.515	35.526	35.537	35.547	35.558	35.569	35.580	35.591	35.601	35.612	35.623	2160
2170	35.623	35.634	35.644	35.655	35.666	35.676	35.687	35.698	35.708	35.719	35.730	2170
2180	35.730	35.740	35.751	35.762	35.772	35.783	35.793	35.804	35.814	35.825	35.836	2180
2190	35.836	35.846	35.857	35.867	35.878	35.888	35.899	35.909	35.920	35.930	35.940	2190
°C	0	1	2	3	4	5	6	7	8	9	10	°C

°C	0	1	2	3	4	5	6	7	8	9	10	°C
2200	35.940	35.951	35.961	35.972	35.982	35.993	36.003	36.013	36.024	36.034	36.044	2200
2210	36.044	36.055	36.065	36.075	36.086	36.096	36.106	36.116	36.127	36.137	36.147	2210
2220	36.147	36.157	36.168	36.178	36.188	36.198	36.208	36.219	36.229	36.239	36.249	2220
2230	36.249	36.259	36.269	36.279	36.289	36.300	36.310	36.320	36.330	36.340	36.350	2230
2240	36.350	36.360	36.370	36.380	36.390	36.400	36.410	36.420	36.430	36.440	36.449	2240
2250	36.449	36.459	36.469	36.479	36.489	36.499	36.509	36.519	36.528	36.538	36.548	2250
2260	36.548	36.558	36.568	36.577	36.587	36.597	36.607	36.616	36.626	36.636	36.645	2260
2270	36.645	36.655	36.665	36.675	36.684	36.694	36.703	36.713	36.723	36.732	36.742	2270
2280	36.742	36.751	36.761	36.771	36.780	36.790	36.799	36.809	36.818	36.828	36.837	2280
2290	36.837	36.846	36.856	36.865	36.875	36.884	36.894	36.903	36.912	36.922	36.931	2290
2300	36.931	36.940	36.950	36.959	36.968	36.978	36.987	36.996	37.005	37.015	37.024	2300
2310	37.024	37.033	37.042	37.051	37.061	37.070						2310
°C	0	1	2	3	4	5	6	7	8	9	10	°C

Thermocouple Analysis

- Open the DATAQ experimental recording file. Click File → Export to Excel. Click Whole File. When Excel opens, click SAVE AS and name your file.
- Use a flash drive to transfer the file to your personal computer. Take the Volt column and convert to mV for each step. Then convert each mV value to temperature using the Type C Thermocouple polynomial.
- The Type C polynomial derived from the above reference table is:

$$y = 0.0218x^3 - 0.8103x^2 + 61.674x + 12.552$$

Replacing Parts

- Large O-Rings: McMaster-Carr Oil-Resistant Buna-N O-Ring Cord Stock, 4mm Wd.
- Small O-Rings: Parker E0603 2-230, EPDM
- Thermocouple Alumina Alloy: ?
- $BaCO_3$: Stetson Chemical?
- Graphite Heater: ?
- Graphite Disk: ?
- Solid MgO: ?
- Hollow MgO: ?