EQUIPMENT BUILD PLAN

AIR & WATER PRESSURE

Magdeburg Hemispheres Without a Pump

Classic Magdeburg hemispheres need a vacuum pump. Bruce's method fills the hemispheres and a long hose with water, carries the sphere up a stairwell while the hose end stays in a bucket below, and lets the hanging water column pull the pressure down inside. It works like a water barometer and gives students the numbers to calculate the force holding the halves together.

> Written from Bruce's original workshop handout. Bruce's final review of this plan is in progress.

DIFFICULTY	BUILD TIME
Intermediate	30 minutes to set up
COST	**SAFETY**
About $15 for tubing, plus a set of Magdeburg hemispheres	Adult build / supervision
GOOD FOR	
Teachers, Makers	

What it shows

No vacuum pump needed: a long hose of water lowers the pressure inside the sphere so strong students cannot pull it apart.

Key ideas: atmospheric pressure, hydrostatic pressure, barometer, pressure and force, partial vacuum

Safety (Adult build / supervision). An adult runs the setup. Work from a stairwell or balcony with a solid railing and never lean over it; keep the area below clear except for the person

minding the bucket. Spilled water makes floors slippery: keep big towels ready and have pullers stand on dry floor. The halves can let go suddenly, so pullers should brace their stance.

CONSTRUCTION

Build it

Materials

- [ ] **Magdeburg hemispheres with shut-off valve** · 1 set
  Standard science-supply set with handles and a valve fitting
- [ ] **Clear plastic tubing, 3/8 in inside diameter** · 38 ft
  Must fit the valve's hose barb
- [ ] **Bucket of water** · 1
- [ ] **Small weight** · 1
  Keeps the hose end down in the bucket

Tools

Bucket

Hose clamp and barb adapter (only if your hose does not fit the valve)

Large towels

1

Gather the equipment

You need a set of Magdeburg hemispheres with a valve, about 38 feet of 3/8 in inside-diameter tubing, a bucket of water and a small weight. Pick a location where you can climb at least 15 to 17 feet above the floor, such as a stairwell with a railing.

2

Attach the hose

Push one end of the tubing onto the hemispheres' valve fitting. If your tubing is a different size, use a barb adapter and hose clamp to join them.

3

Fill the hemispheres with water

Hold the two halves together under water in the bucket so they fill completely, then close the valve. Keep holding them together until everything is ready.

4

Fill the hose completely

Fill the whole hose with water so no air bubbles remain. Put its free end in the bucket with the small weight so it stays below the surface.

5

Carry the sphere up

Carry the water-filled sphere and the hose up as high as you can while a helper makes sure the bottom end never leaves the bucket. If it lifts out even briefly, an air bubble works up the tube and the water drains.

6

Open the valve

At the top, open the valve. The water in the hose is pulled down by gravity, but air cannot get in to replace it, so the pressure inside the sphere drops.

7

Try to pull it apart

Have volunteers grab the handles and pull. At about 17 feet up, the sphere is held together by roughly half the force of a full vacuum, more than strong students can usually manage.

8

Release the sphere

Bring the sphere back down near the bucket so the pressure inside rises again, and the halves will come apart easily. Do this over the bucket or towels to catch the water.

THE PHYSICS

How it works

In the 1650s Otto von Guericke (1602-1686) of Magdeburg, Germany pumped the air out of two large metal hemispheres, and two teams of eight horses could not pull them apart. The air outside was pushing the halves together with nothing pushing back from inside.

The atmosphere presses with about 14.7 pounds per square inch. A column of water about 33.9 feet tall weighs the same per square inch, so every 2.3 feet of water corresponds to about 1 psi. When the water in the hose hangs below the sphere and cannot be replaced by air, it lowers the pressure inside by about 1 psi for every 2.3 feet of height.

With the sphere 17 feet above the bucket, the pressure inside drops by about 17 / 2.3 = 7.3 psi, about half an atmosphere. How hard the halves are to pull apart depends on the sphere's size: a 4 inch sphere (about 12.6 square inches across its middle) takes about 185 pounds with a full vacuum and about 93

Using it

- Before climbing, have students calculate the expected pressure drop from the height and estimate the pulling force using the sphere's cross-section area.
- Ask why the bottom end of the hose must stay under water.
- Compare this method with a vacuum pump. Which removes more air, and how could you get closer to a full vacuum?
- Connect it to a mercury or water barometer and to why a suction pump cannot lift water more than about 34 feet.
- Try different heights and see at what point the strongest volunteer can pull the sphere apart.

pounds at 17 feet. Going higher than about 34 feet would not help, because the water column would break and leave an empty space at the top of the hose, just like the top of a water barometer.

GO FURTHER

Variations

- Smaller hose: Bruce also tried 1/4 in outside-diameter aquarium tubing joined to the valve with an adapter and hose clamp. At 16 feet strong students pulled the sphere apart, but at about 30 feet they could not. He prefers the 3/8 in hose.
- Use the same setup to crush cans or plastic bottles instead of holding hemispheres.
- Replace the hemispheres with a vacuum gauge and watch the reading change as you climb the stairs.

IF IT DOESN'T WORK

Troubleshooting

IF THIS HAPPENS	TRY THIS
The sphere comes apart easily.	Check that the hose is completely full of water with no bubbles, that the bottom end stayed under water, and that you are high enough.
The water drains out of the hose.	The hose end lifted out of the bucket or a fitting is leaking air. Refill and clamp the fittings.
Bubbles appear in the hose at the top.	Some dissolved air comes out of water at low pressure. Small bubbles are normal; refill if a large gap forms.

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