ISS Research Design Challenge: CELERE

Capillary Effects on Liquids Exploratory Research Experiments

https://spaceflightsystems.grc.nasa.gov/education-outreach/celere/

2019 Handbook

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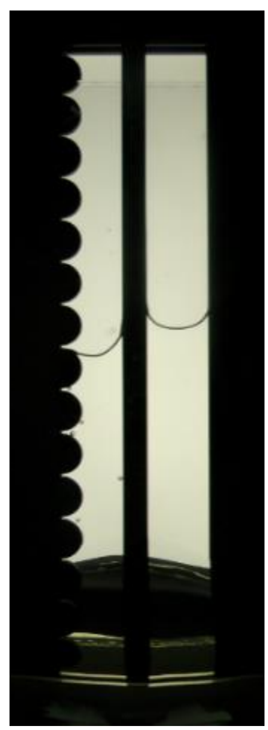
Contents

This section and the next are VERY IMPORTANT!!!

The tutorial, drawing template, entry form, and flyer are separate files and can be downloaded from http://tinyurl.com/SEECmicrogravity or https://spaceflightsystems.grc.nasa.gov/education-outreach/celere/how-to-apply/.

Design Challenge Overview



CELERE is a joint educational program of NASA and Portland State University (PSU) enabling students to participate in microgravity research on capillary action related to that conducted on the International Space Station (ISS). The students create their own experiments using Computer-Aided Design (CAD) with a provided template and *DraftSight* software, which can be downloaded for free from www.3ds.com/products-services/draftsight-cad-software/free-download/. Experiment proposals, which consist primarily of a single CAD drawing, are submitted to NASA. The test cells are then manufactured by PSU using the drawings and a computer-controlled laser cutter. Each experiment is conducted in PSU's Dryden Drop Tower (www.pdx.edu/dryden-drop-tower/), where it will fall 22 meters (73 feet) and experience 2.1 seconds of apparent near weightlessness, i.e., microgravity. Video and still images from each drop are provided online for student analysis and the reporting of results, for example in a science fair or class presentation. The example image shows a 2013 experiment (from Columbus, GA) during the middle of the drop, where the scalloped channel wall has slowed the upward motion of the oil (relative to the oil's motion in the straight-walled channel).

CELERE enables students to participate in research related to space station science and learn about computer technology (e.g., CAD), both of which can inspire the pursuit of STEM careers - where STEM stands for Science, Technology, Engineering, and Mathematics. Boy Scouts could use the CAD drawing toward completion of the *Drafting* merit badge. And selection in a nation-wide NASA design challenge is an accomplishment worth noting on college applications!

Capillary Action

NASA is very interested in capillary action because of its importance in liquid systems on spacecraft. On Earth, liquids naturally flow downward because of gravity and equipment is designed and built to take advantage of that natural process. For example, cars draw gasoline from the bottom of the fuel tank. But in microgravity, liquids naturally flow because of capillary action making it important for propellant, water processing, thermal control systems – as well as in some materials processing.

Capillary action happens when the molecules of a liquid (like water) are more attracted to a surface than to each other. In paper towels, the molecules move along tiny fibers. In plants (like celery), they move upward through narrow tubes called capillaries. For more basic information about capillary action, see for example:

http://water.usgs.gov/edu/capillaryaction.html
http://web.mit.edu/nnf/education/wettability/index1.html
http://hyperphysics.phy-astr.gsu.edu/hbase/surten2.html#c4

Capillary action can be difficult to observe on Earth because of gravity, except in small capillaries. But while experiments fall in a drop tower, where there seems to be almost no gravity, capillary effects are easy to see and study.

Drop Tower

In PSU's Dryden Drop Tower, your experiment will be dropped down a tall shaft and while it is falling, it will behave as if there is nearly no gravity – of course neglecting the fall! Gravity will still be present, but our sensation of gravity and weight comes from a resistance to its pull, for example because of the floor holding us up. But while freely falling, we feel weightless and that is the basis for many amusement park rides. This works because of the surprising situation where all objects fall at the same acceleration unless acted upon by another force. As one result, the astronauts and the International Space Station fall together (around the Earth) such that the astronauts float within the space station. This happens even though the space station is so close to the Earth that gravity there (in a low-Earth orbit) is only about 10% less than that on the planet's surface. While this is space science, the concept of apparent near weightlessness through free fall, i.e., microgravity, was put to practical use in the late 1700s when shot towers were first built to produce superior shot for hunting. In those towers, droplets of liquid lead became spherical because of the surface tension resulting from the liquid's attraction to itself. You can learn more about microgravity at:

http://www.nasa.gov/centers/glenn/shuttlestation/station/microgex.html
http://www.nasa.gov/audience/foreducators/microgravity/home/index.html

PSU

PSU's Prof. Mark Weislogel (http://www.pdx.edu/profile/meet-professor-mark-weislogel) is a world leader in the study of capillary action and with NASA support has had such experiments conducted in drop towers, on the space shuttle, on the Russian *Mir* space station, and the International Space Station (ISS) where the following are two examples of his ISS experiments:

Capillary Channel Flow (CCF) http://issresearchproject.grc.nasa.gov/MSG/CCF/
Capillary Flow Experiment (CFE) http://issresearchproject.grc.nasa.gov/MWA/CFE/

Now you can design your own microgravity experiment and investigate capillary action just like Prof. Weislogel and the astronauts. Begin by visiting the CELERE web site at https://spaceflightsystems.grc.nasa.gov/education-outreach/celere/ and reading this guide!

Many astronauts have participated in microgravity studies of capillary action, including for example the following for CFE: Joe Acaba, Clay Anderson, Dan Burbank, Chris Cassidy, Cady Coleman, Tracy Caldwell Dyson, Mike Fincke, Kevin Ford, Mike Fossum, Mike Hopkins, Scott Kelly, Mike Lopez-Alegria, Bill McArthur, Tom Marshburn, Karen Nyberg, Don Pettit, Shannon Walker, Peggy Whitson, Jeff Williams, and Sunita Williams (shown above operating CFE on the space station).

Eligibility

The design challenge is for youth in grades 8-12, who may participate as individuals or in teams of any size. Teams may also include younger students as long as there is at least one team member in grades 8-12, where this option can facilitate the participation of informal science clubs, Scouts, etc. Youth are free to get help from adults, for example in creating their CAD drawing. But this program is for youth.

The program is limited to students from the United States. It is open to all fifty states, the District of Columbia, Puerto Rico, American Samoa, Guam, the Northern Mariana Islands, and the U.S. Virgin Islands. Students in other countries – even if U.S. citizens - are ineligible, with the exception of those attending DODEA schools for the children of U.S. military personnel.

Whether as an individual participant or team member, a student may be associated with at most a single CELERE 2019 proposal. Furthermore, a maximum of 7 experiment proposals may be submitted to NASA by a single school or organization for the 2019 challenge. But organizations can have greater participation if they prescreen the proposals and only forward what they believe to be the best to NASA.

Selection

Since the initiation of this design challenge, 100% of the entries received were selected for fabrication and testing in microgravity. However, this was often after the teams were directed to revise their CAD drawings because they failed to meet the design requirements specified in this document. **Please know that 2019 submissions which violate the design requirements may be rejected** to reduce the NASA and PSU workload associated with the challenge.

Revisions were requested of roughly one third of the CELERE entries submitted last year, so close attention should be paid to the design requirements and common mistakes described in this document. Failure to do so may easily lead to rejection.

NASA will not check drawings to make sure that they are acceptable prior to the entry deadline, but will answer questions about the design requirements. Nonetheless, it is the submitting team's responsibility to review this document and ensure that the requirements are met.

If the design and submission requirements are met, the odds of selection in 2019 are quite high, where at least one qualifying entry is guaranteed for each state, etc. listed under 'Eligibility.' This guarantee includes selection of at least one qualifying entry from an overseas DODEA school. Selection is also guaranteed for at least one qualifying entry from a Bureau of Indian Education (BIE) school. In past years, i.e., 2013-2018, there have only been participants from 20 states, Puerto Rico, and one overseas DODEA school (in Germany), so your entry could easily be the first from your locale.

Conference

A small number of CELERE participants - based on their experiment design, data analysis, and written report - will be invited to present their results in a student poster session at the 2019 meeting of the American Society for Gravitational and Space Research (ASGSR, www.asgsr.org) on Sat., November 23. It is expected that limited financial support will be available to help the invited non-local students travel to Denver, Colorado for this purpose.

Cost

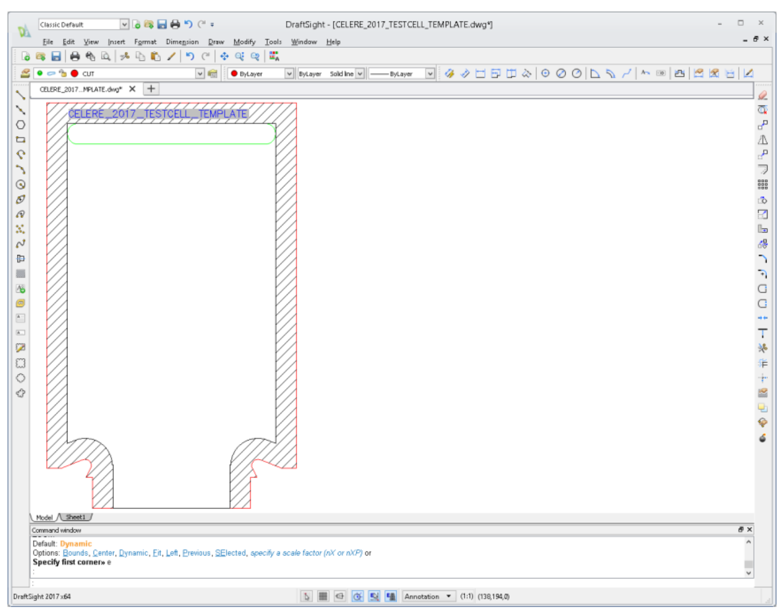
There is no cost to participate in CELERE other than the optional conference travel.

Files & Educational Resources

Access CELERE files and various educational resources related to microgravity via http://tinyurl.com/SEECmicrogravity.

Key Changes from 2018

- The 2019 schedule has been adjusted as a result of the partial shutdown of the federal government. The submission deadlines for 2019 are:
  - March 10 proposal (i.e., CAD drawing and entry form)
  - May 5 written report on the results
- The proposal, report, and other communication with NASA must be in English.
- The drawing template has been updated. Please use the 2019 drawing template which can be downloaded from:
  http://tinyurl.com/SEECmicrogravity
  https://spaceflightsystems.grc.nasa.gov/education-outreach/celere/how-to-apply/
- The other supporting documents – including this handbook, the tutorial, and entry form - have also been updated.
- The freely-downloadable *DraftSight* software upon which the tutorial is based has been and continues to be updated.

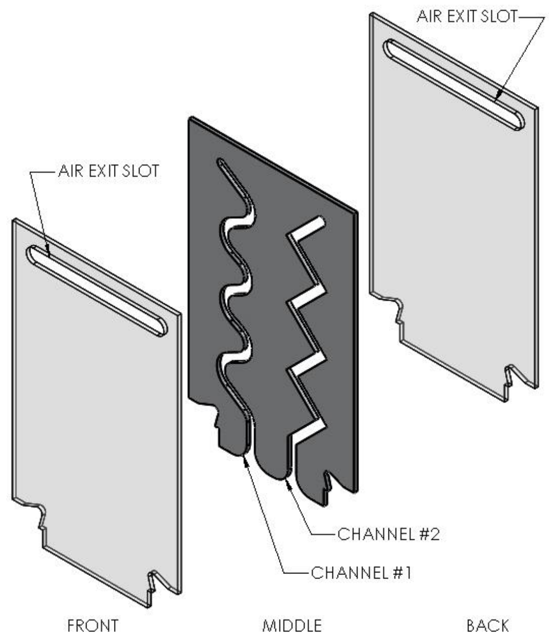
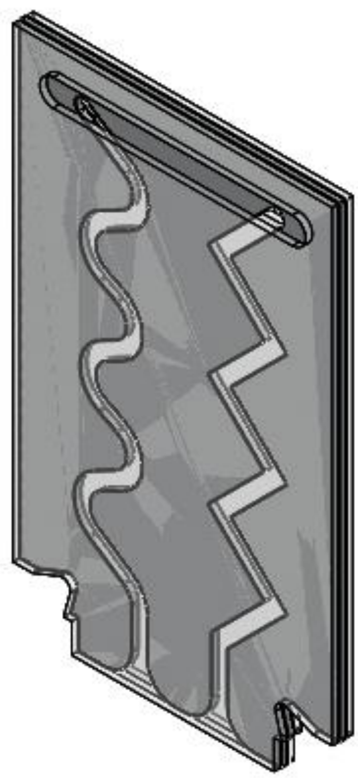


How to Participate

- **Preparation and Submission**
  - Explore the CELERE website at http://spaceflightsystems.grc.nasa.gov/CELERE/.
  - If you are a Facebook user, 'like' the CELERE page at www.facebook.com/NASA.celere.
  - Read this handbook.
  - Learn about capillary action, e.g., through:
    - http://ga.water.usgs.gov/edu/capillaryaction.html
    - http://hyperphysics.phy-astr.gsu.edu/hbase/surten2.html#c4
    - http://web.mit.edu/nnf/education/wettability/index1.html
  - Review past experiments through the appendix of this handbook at a minimum, and ideally at https://spaceflightsystems.grc.nasa.gov/education-outreach/celere/celere-videos/.
  - Download the CELERE 2018 tutorial from https://spaceflightsystems.grc.nasa.gov/education-outreach/celere/how-to-apply/.
  - Download the 2019 drawing template from https://spaceflightsystems.grc.nasa.gov/education-outreach/celere/how-to-apply/. The use of past templates is unacceptable.
  - From https://www.3ds.com/products-services/draftsight-cad-software/free-download/, download the *Draftsight* CAD software and go through the CELERE tutorial. You may use other CAD software that works with 'dwg' files, but the tutorial is based on the free *Draftsight* software.
  - Review the design requirements and common mistakes in this handbook.
  - Develop your research question.
  - Design your test cell so that (1) the results will answer your research question and (2) it is different from the past CELERE experiments shown in the appendix.
  - Download the entry form from https://spaceflightsystems.grc.nasa.gov/education-outreach/celere/how-to-apply/ and fill it out.
  - Verify that all design requirements are fully met or risk rejection!
  - E-mail the drawing file and entry form to celere@lists.nasa.gov (where this step might be done by your teacher/advisor) by March 10.
- **Testing and Analysis**
  - *Selected experiments are normally conducted during the month of their submission deadline.*
  - When notified, download the results from http://celere.mme.pdx.edu/. Note that the video files are not standard, but can be viewed using *VLC Media Player*, which can be freely downloaded from http://www.videolan.org/vlc/index.html.
  - Analyze the results by comparing the capillary motion in your test cell's channels. You can determine the position of the oil in each channel as a function of time (e.g., knowing that high-speed video includes 60 frames per second). The position can be determined in pixels, e.g., using Microsoft Paint, which shows the position of the crosshairs in pixels, and then converted later into millimeters.
  - From the position data, average speeds can easily be determined.
- **Reporting**
  - Prepare a written report about what you learned, and e-mail it by May 5 to celere@lists.nasa.gov (where the submission might be done by your teacher/advisor). The report should include discussion of what was good about the CELERE design challenge and what needs improvement.
  - If invited, optionally present your results in a student poster session at the 2019 meeting of the American Society for Gravitational and Space Research (ASGSR, www.asgsr.org) on Sat., Nov. 23. It is expected that limited financial support will be available to help the invited non-local students travel to Denver, CO for this purpose.

Note that product references do not indicate an endorsement on the part of NASA or the federal government.

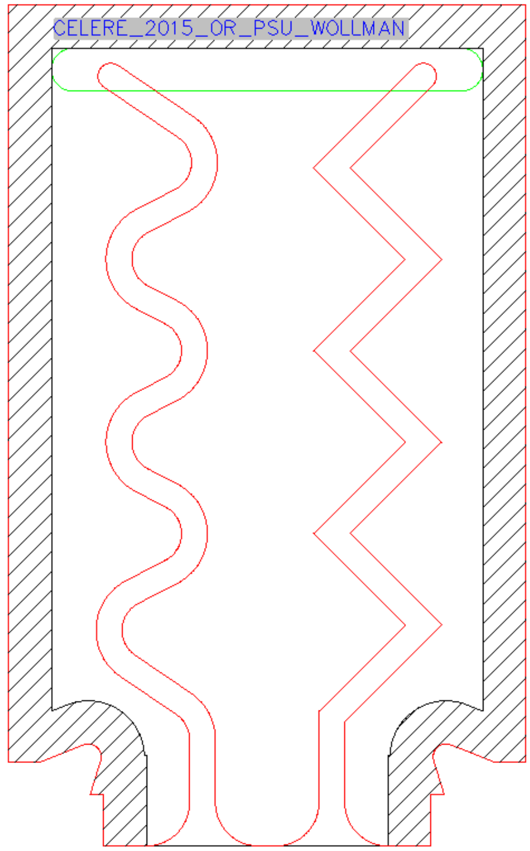
Experiment Hardware, Testing, and Analysis

Instructions & comments	Screen shots, images, and diagrams
Computer-Aided Design (CAD) image of a sample test cell showing the three layers separated in an "exploded" view. CELERE participants design the black middle layer which will be sandwiched between the clear front and black plates. Those two standard plates have air vents at their top. **VERY IMPORTANT!** The channels cut in the middle layer must extend from the base to the air vents to enable the capillary action. The liquid won't rise if (1) the liquid can't enter the channels or (2) the air above the liquid can't escape.	
CAD image of the example test cell assembled, with the three layers together.	 ALL THREE LAYERS TOGETHER

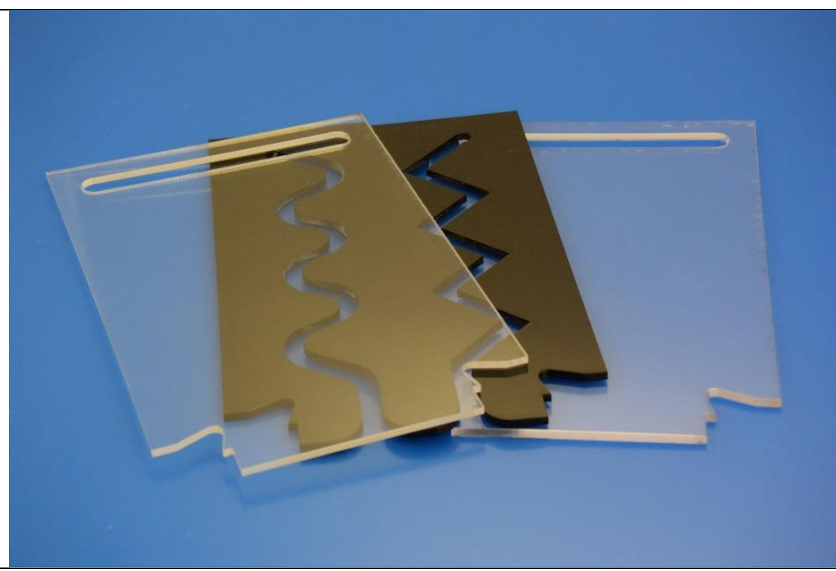
You will use the free CAD software package, *DraftSight*, and a provided template to design and draw the middle layer of your test cell. Your submitted drawing will be used to fabricate the middle layer. In this image, the black is the template for the middle layer, the green shows the air vents in the front and back layers, and the red shows the channels in which the liquid will rise.

Draftsight can be freely downloaded for Windows, Mac, etc. from: https://www.3ds.com/products-services/draftsight-cad-software/free-download/ but it is not compatible with Windows 98. Earlier versions of the software can be downloaded elsewhere, but they may or may not function.

Please make sure to use the 2019 drawing template which is available for download from:
http://tinyurl.com/SEECmicrogravity
https://spaceflightsystems.grc.nasa.gov/education-outreach/celere/how-to-apply/

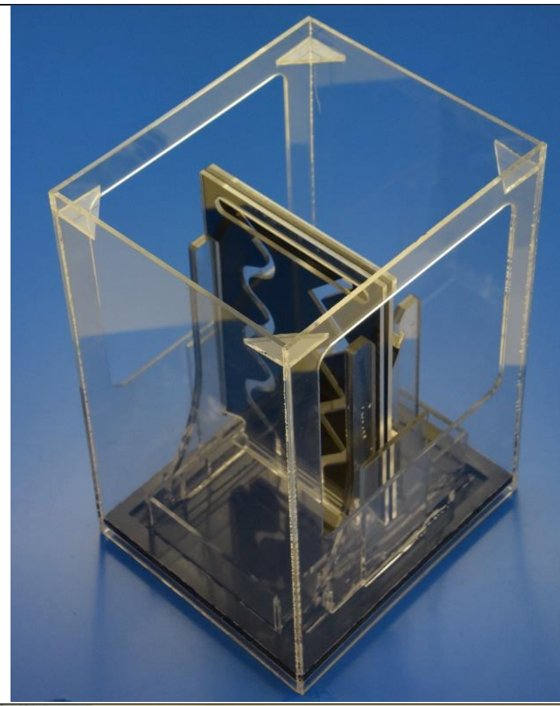


Portland State University (PSU) will cut your team's middle layer, with its unique channels, out of black acrylic using a computer-controlled laser cutter and your CAD drawing.

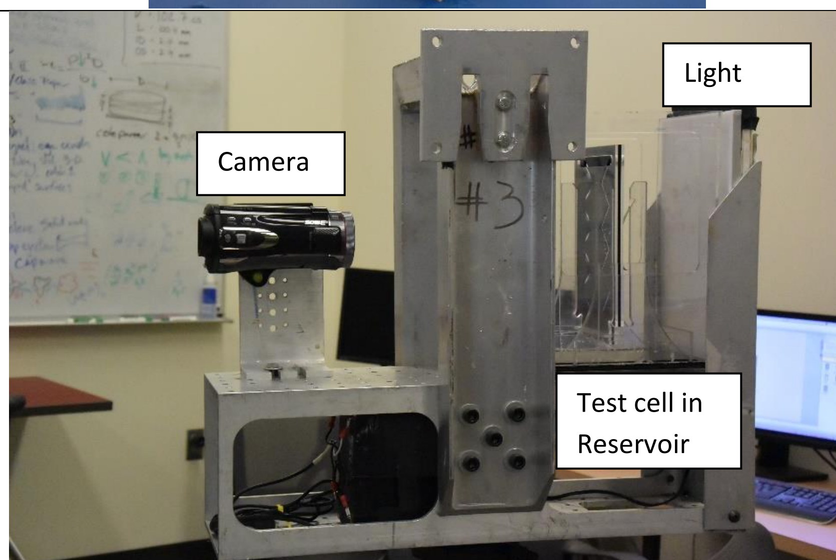


PSU will assemble your test cell and mount it in a container so that its base is within a reservoir of a low-viscosity silicon oil. This oil is attracted to the acrylic and will respond quickly during the short duration of the drop.

With this approach, the fluid is not an acceptable variable in your CELERE experiment. Instead, you will be studying the differences in the capillary motion in each of your test cell's channels. In the example test cell shown, the effect of curved and sharp corners are compared, i.e., in the two zigzag channels.



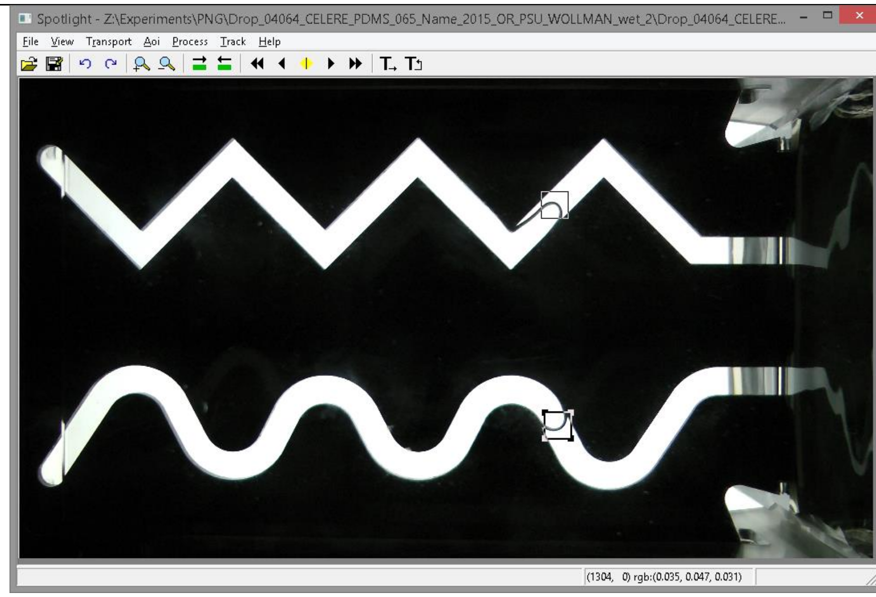
The test cell and reservoir will be placed on an experiment rig between a video camera and a light source, such that the test cell will be back lit.



The experiment rig will be placed inside a drag shield at the top of PSU's Dryden Drop Tower. When everything is ready, the drag shield and the experiment rig will be dropped and fall for 2.1 seconds during which time it will experience apparent near weightlessness (i.e., microgravity). During the drop, the camera will image the capillary rise of the liquid inside the channels.

Sample images every 0.3 second.

One option for analyzing your results is through NASA's *Spotlight* software, which can be freely downloaded at: http://microgravity.grc.nasa.gov/spotlight/ In this example, *Spotlight-16* is being used to track the location of the menisci, i.e., liquid-air interface, from frame to frame as it rises within the channels. In this image, up is the left and down is to the right. Furthermore, it is the lowest (farthest right) point on the meniscus surface that is being tracked. Note that *Spotlight* is not currently supported and *Spotlight-8* is not compatible with current versions of *Microsoft Windows*.



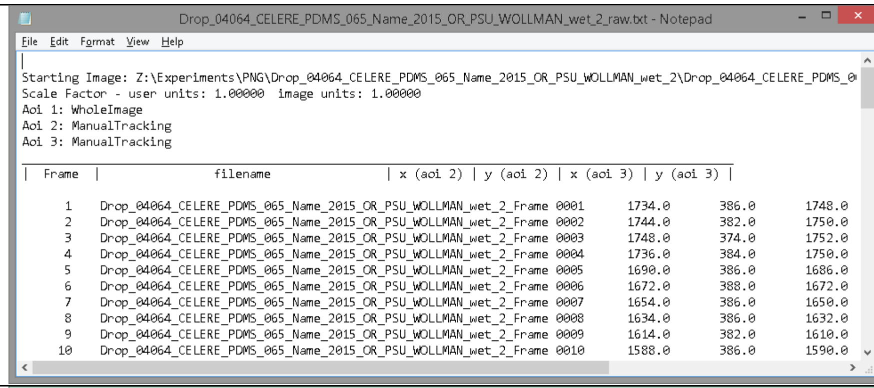
Tracker is another free software package for video analysis; it can be downloaded from: https://www.cabrillo.edu/~dbrown/tracker/

But you can also make position measurements with simple software, like *Microsoft Paint*, which continually reveals the position of its crosshairs (e.g., in the bottom left of the window). Simply load an image, move the crosshairs to each desired position and write down their values (i.e., by hand). Repeat to track the positions as a function of time.

You can even make measurements manually by taping a transparent overlay to your computer monitor and marking the positions using a permanent marker. You can make measurements for multiple images (i.e., times) using the same transparency by marking each position with the image number.

This task can be simplified by only making measurements at every tenth frame (for example), where that equates to every one sixth of a second.

Spotlight can output a data file, which in this example includes the position of the meniscus for each sequential frame. With CELERE's high-speed video, there are 60 frames per second.



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Drop_04064_CELERE_PDMS_065_Name_2015_OR_PSU_WOLLMAN_wet_2_raw.txt - Notepad
File  Edit  Format  View  Help

Starting Image: Z:\Experiments\PNG\Drop_04064_CELERE_PDMS_065_Name_2015_OR_PSU_WOLLMAN_wet_2\Drop_04064_CELERE_PDMS_0
Scale Factor - user units: 1.00000  image units: 1.00000
Aoi 1: WholeImage
Aoi 2: ManualTracking
Aoi 3: ManualTracking

| Frame |              filename                 | x (aoi 2) | y (aoi 2) | x (aoi 3) | y (aoi 3) |

    1   Drop_04064_CELERE_PDMS_065_Name_2015_OR_PSU_WOLLMAN_wet_2_Frame 0001    1734.0    386.0    1748.0
    2   Drop_04064_CELERE_PDMS_065_Name_2015_OR_PSU_WOLLMAN_wet_2_Frame 0002    1744.0    382.0    1750.0
    3   Drop_04064_CELERE_PDMS_065_Name_2015_OR_PSU_WOLLMAN_wet_2_Frame 0003    1748.0    374.0    1752.0
    4   Drop_04064_CELERE_PDMS_065_Name_2015_OR_PSU_WOLLMAN_wet_2_Frame 0004    1736.0    384.0    1750.0
    5   Drop_04064_CELERE_PDMS_065_Name_2015_OR_PSU_WOLLMAN_wet_2_Frame 0005    1690.0    386.0    1686.0
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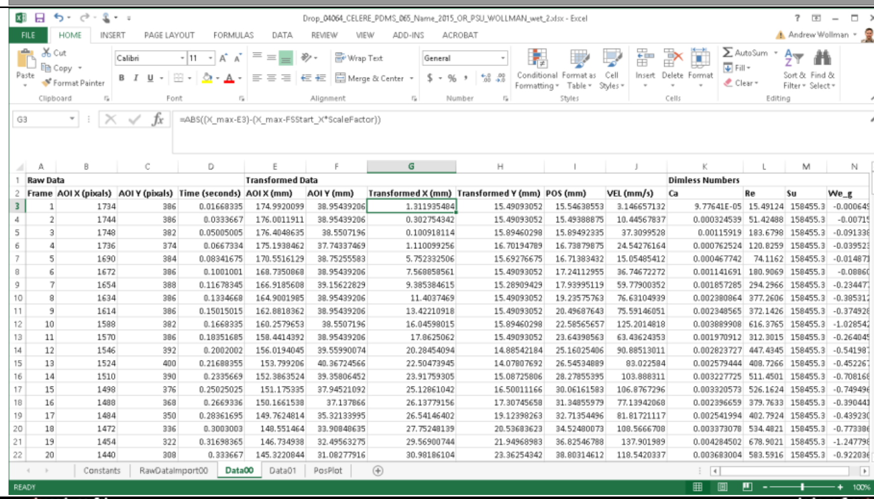
    8   Drop_04064_CELERE_PDMS_065_Name_2015_OR_PSU_WOLLMAN_wet_2_Frame 0008    1634.0    386.0    1632.0
    9   Drop_04064_CELERE_PDMS_065_Name_2015_OR_PSU_WOLLMAN_wet_2_Frame 0009    1614.0    382.0    1610.0
   10   Drop_04064_CELERE_PDMS_065_Name_2015_OR_PSU_WOLLMAN_wet_2_Frame 0010    1588.0    386.0    1590.0
```

Spotlight data files can be imported into *Microsoft Excel* or similar software for data analysis and plotting.

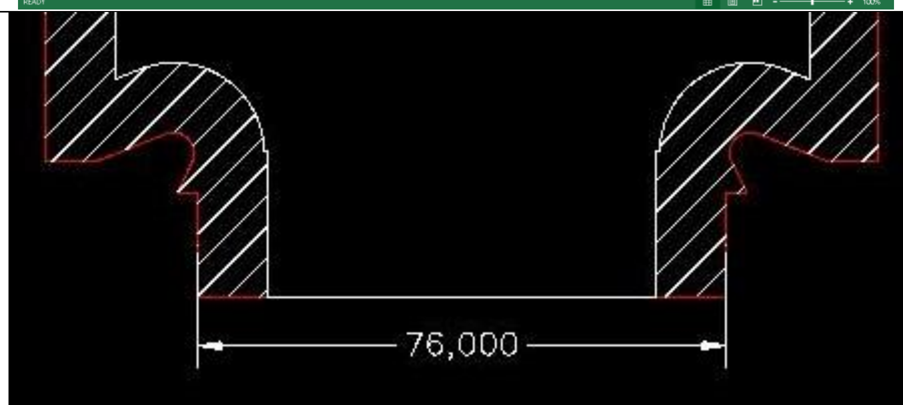


=ABS((X_max-E3)-(X_max-FSStart_X*ScaleFactor))

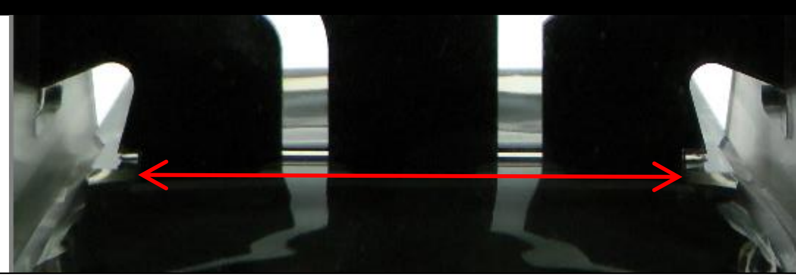
Raw Data				Transformed Data						Dimless Numbers			
Frame	AOI X (pixals)	AOI Y (pixals)	Time (seconds)	AOI X (mm)	AOI Y (mm)	Transformed X (mm)	Transformed Y (mm)	POS (mm)	VEL (mm/s)	Ca	Re	Su	We_g
1	1734	386	0.01668335	174.9920099	38.95439206	1.311935484	15.49093052	15.54638553	3.146657132	9.77641E-05	15.49124	158455.3	-0.00064
2	1744	386	0.0333667	176.0011911	38.95439206	0.302754342	15.49093052	15.49388875	10.44567837	0.000324539	51.42488	158455.3	-0.0071
3	1748	382	0.05005005	176.4048635	38.5507196	0.100918114	15.89460298	15.89492335	37.3099528	0.00115919	183.6798	158455.3	-0.09133
4	1736	374	0.0667334	175.1938462	37.74337469	1.110099256	16.70194789	16.73879875	24.54276164	0.000762524	120.8259	158455.3	-0.03952
5	1690	384	0.08341675	170.5516129	38.75255583	5.752332506	15.69276675	16.71383432	15.05485412	0.000467742	74.1162	158455.3	-0.01487
6	1672	386	0.1001001	168.7350868	38.95439206	7.568858561	15.49093052	17.24112955	36.74672272	0.001141691	180.9069	158455.3	-0.0886
7	1654	388	0.11678345	166.9185608	39.15622829	9.385384615	15.28909429	17.93995119	59.77900352	0.001857285	294.2966	158455.3	-0.23447
8	1634	386	0.1334668	164.9001985	38.95439206	11.4037469	15.49093052	19.23575763	76.63104939	0.002380864	377.2606	158455.3	-0.38531
9	1614	386	0.15015015	162.8818362	38.95439206	13.42210918	15.49093052	20.49687643	75.59146051	0.002348565	372.1426	158455.3	-0.37492
10	1588	382	0.1668335	160.2579653	38.5507196	16.04598015	15.89460298	22.58565657	125.2014818	0.003889908	616.3765	158455.3	-1.02854
11	1570	386	0.18351685	158.4414392	38.95439206	17.8625062	15.49093052	23.64398563	63.43624353	0.001970912	312.3015	158455.3	-0.26404
12	1546	392	0.2002002	156.0194045	39.55990074	20.28454094	14.88542184	25.16025406	90.88513011	0.002823727	447.4345	158455.3	-0.54198
13	1524	400	0.21688355	153.799206	40.36724566	22.50473945	14.07807692	26.54534889	83.022584	0.002579444	408.7266	158455.3	-0.45226
14	1510	390	0.2335669	152.3863524	39.35806452	23.91759305	15.08725806	28.27855395	103.888311	0.003227725	511.4501	158455.3	-0.70816
15	1498	376	0.25025025	151.175335	37.94521092	25.12861042	16.50011166	30.06161583	106.8767296	0.003320573	526.1624	158455.3	-0.74949
16	1488	368	0.2669336	150.1661538	37.137866	26.13779156	17.30745658	31.34855979	77.13942068	0.002396659	379.7633	158455.3	-0.39044
17	1484	350	0.28361695	149.7624814	35.32133995	26.54146402	19.12398263	32.71354496	81.81721117	0.002541994	402.7924	158455.3	-0.43923
18	1472	336	0.3003003	148.551464	33.90848635	27.75248139	20.53683623	34.52480073	108.5666708	0.003373078	534.4821	158455.3	-0.77338
19	1454	322	0.31698365	146.734938	32.49563275	29.56900744	21.94968983	36.82546788	137.901989	0.004284502	678.9021	158455.3	-1.24779
20	1440	308	0.333667	145.3220844	31.08277916	30.98186104	23.36254342	38.80314612	118.5420337	0.003683004	583.5916	158455.3	-0.92203

Constants RawDataImport00 Data00 Data01 PosPlot

If you measure the capillary motion, you will need to correctly scale your measurements, e.g., converting pixels to millimeters. The three test cell plates are 76 mm across at their base, so you can measure that distance (e.g., in pixels) to determine the scaling factor.



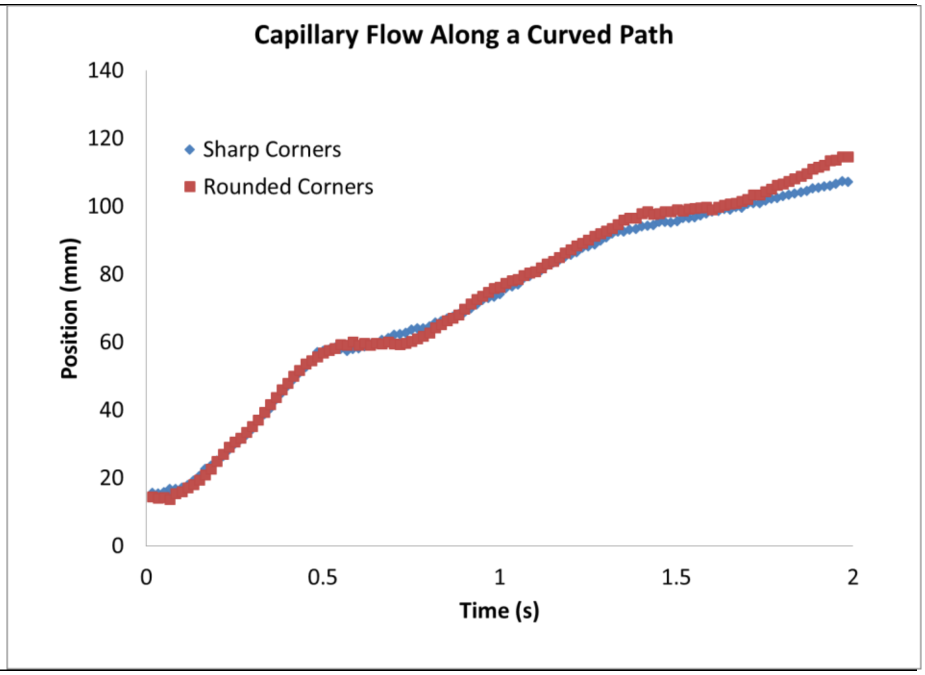
Measurement to be made to calculate a scaling factor, as shown by the double-ended red arrow. The distance is 76 mm across as shown in the preceding figure.



In this example plot, the fluid rise within the channels can be seen. The blue and red reveal the rise in the rounded (left) and sharp (right) channels, respectively (as seen in the images on the previous pages).

The results show that the fluid generally slowed down at each corner, but more so in the sharp cornered channel. Therefore the fluid travels farther in the round cornered channel.

Detailed analysis such as this is not required for CELERE, but all participants are required to briefly report on their findings.



Design Requirements

These requirements are <u>**VERY IMPORTANT**</u> because they will be used in selecting experiments for fabrication and testing. **You risk rejection if you do not closely follow these requirements!**

Experiment requirements

- ☐ The experiment must have a research question that is specific to the test cell's channels,
- ☐ the research question must address the effect of the channel shape and/or size on the capillary flow,
- ☐ the experiment must include only one test cell (and thus only one drawing),
- ☐ the test cell must have at least 2 channels,
- ☐ the channels should ideally differ in a single way,
- ☐ the variation between the channels must address the research question,
- ☐ the experiment must differ from the past CELERE experiments depicted in this handbook's appendix,
- ☐ the proposal, report, and other communication with NASA must be in English, and
- ☐ the drawing and entry files must be named as:

  CELERE_2019_<StateAbbrev>_<OrgAbbrev>_<AdvisorLastName>_<ParticipantAbbrev>

  where the drawing is a dwg file and the entry file is in a pdf or doc format. Furthermore, sufficient abbreviation is required that the file name fits within the drawing's test cell outline in a single line.

Drawing requirements

- ☐ Cut lines must be in the CUT layer (which normally appears in red in *DraftSight*),
- ☐ cut lines must be continuous (i.e., without gaps),
- ☐ cut lines must begin at the test cell base, pass <u>into</u> the green-outlined vent zone, and return to the test cell base,
- ☐ cut lines must not cross themselves or each other,
- ☐ cut lines must not touch the border zone (marked with the diagonal pattern) including its inner edge,
- ☐ channels must be at least 3 mm apart,
- ☐ channels may not merge - so 'islands' (i.e., loose cut pieces used in the test cell) are not allowed, and
- ☐ nothing (including text) can be outside of the boundaries of the test cell.

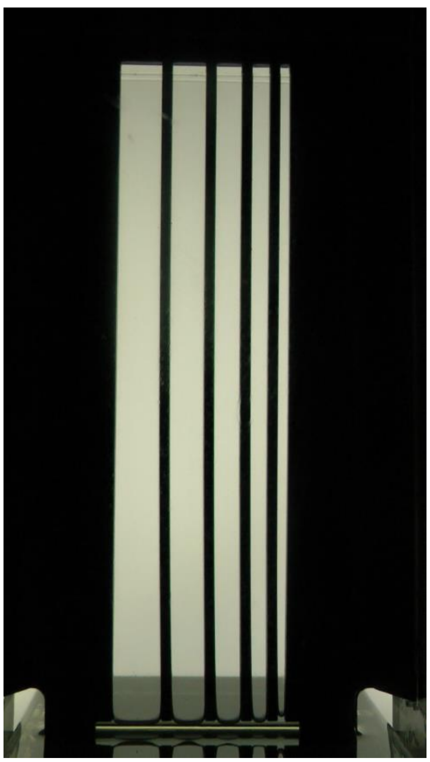
Discussion

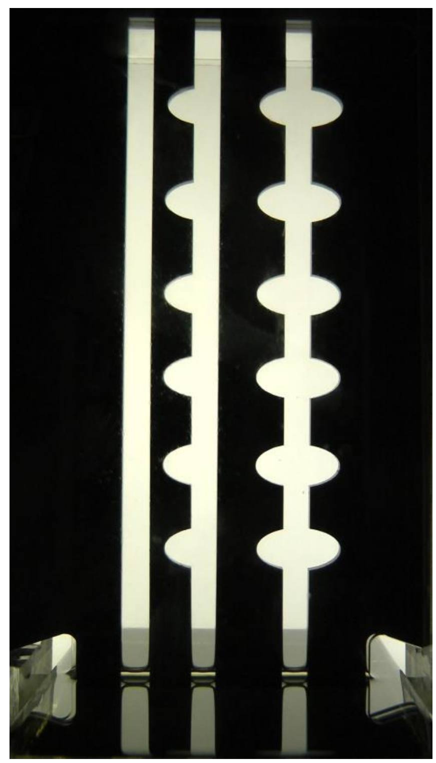
For the CELERE Design Challenge, the research question must be about the effect of the channel's shape and/or size on the capillary flow. The liquid will not be accepted as a parameter because a low-viscosity and thus fast-acting oil will be used for all CELERE experiments. A research question is required for each CELERE submission, but hypotheses are optional and will not be used as the basis for selection. Research questions are expected to be specific to the experiment. Generic questions such as "in which channel will the oil rise most quickly?" are inappropriate. An example of a good research question is "in zigzag channels, will the oil rise more quickly when the corners are curved or sharp?"

CELERE experiments must have two or more channels because they are conducted with a single test cell. Therefore, two or more channels are required to allow comparison of the resulting behavior. The other key is that the channels should ideally differ from each other in only one way so that the cause of any differences in the capillary action will be obvious. If the channels differ in two or more ways, then it won't be clear which factor caused the resulting differences in the capillary flow.

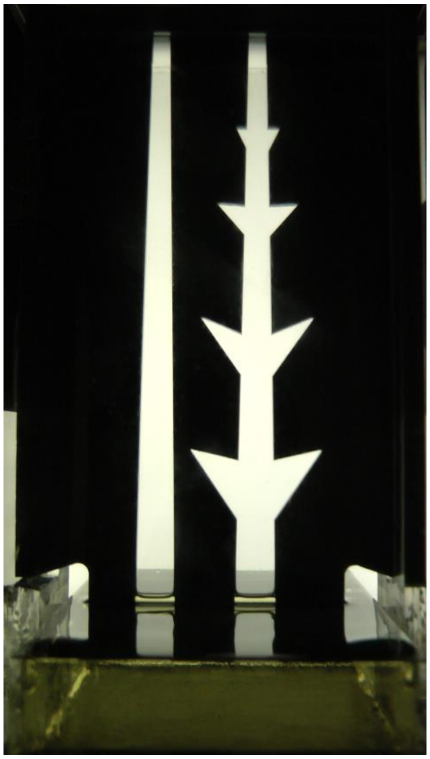
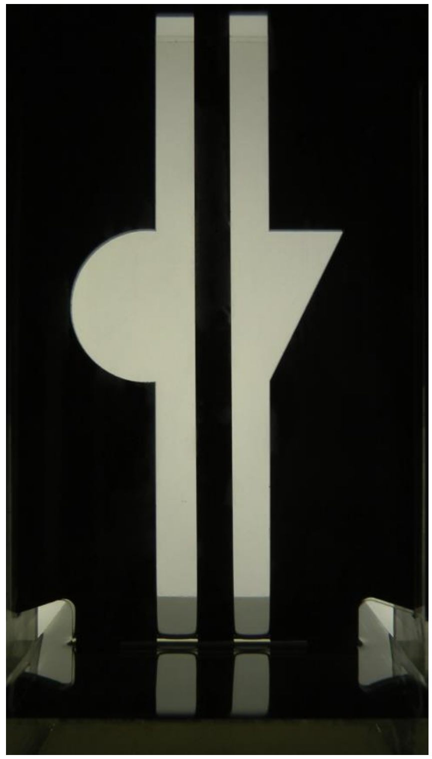
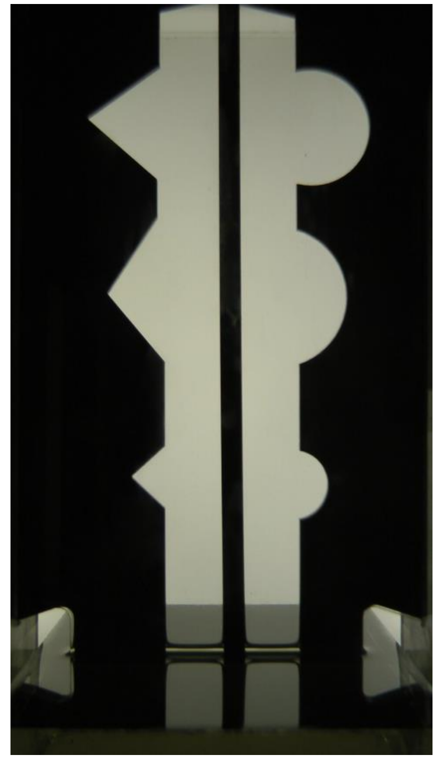
Of course, the research question must be answered by successful conduct of the experiment, i.e., with the variation between the channels. For example, if the research question is *"in zigzag channels, will the oil rise more quickly when the corners are curved or sharp?"*, then the experiment must have zigzag channel with both curved and sharp corners.

Some examples of past experiments which meet the experiment requirements are shown below. The experiment shown on the left is arguably the simplest example, where it clearly examines the effect of the channel width on the capillary action. In the center experiment, the effect of the curvature on the capillary action is explored through a comparison between the oil's motion in curved and straight channels. Meanwhile, the experiment shown on the right explores the effect of elliptical cavities on the capillary motion.

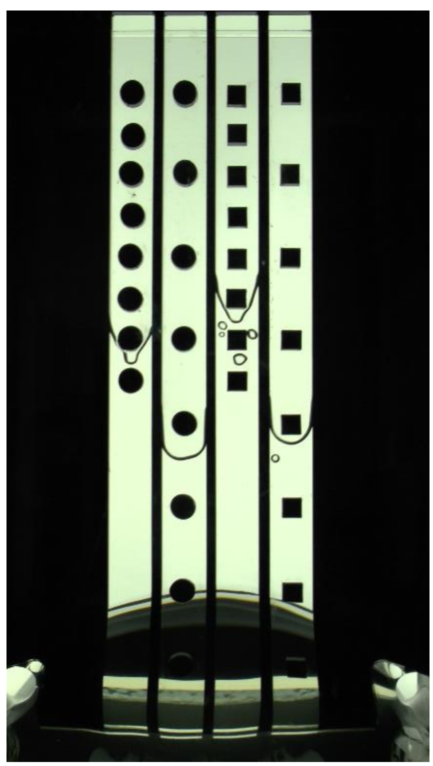
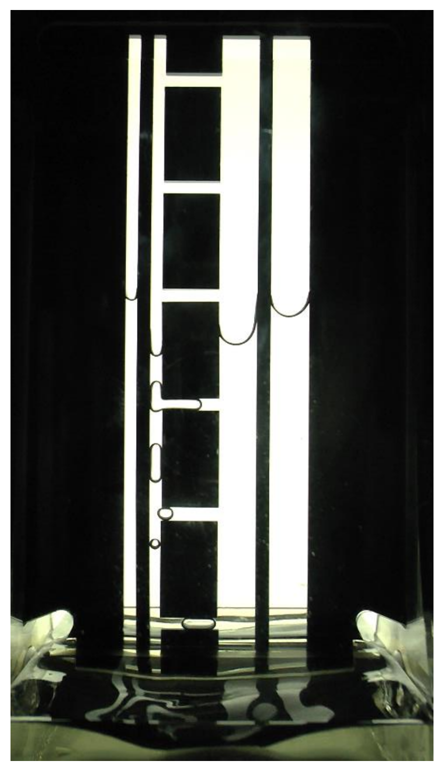




In the previous examples, the comparison is consistently made against a straight vertical channel. While acceptable and appropriate for many experiments, that shape is not required for a good CELERE experiment. For example, the experiment shown subsequently (on the left) has channels which narrow with height. But the experiment can still clearly reveal the effect of the triangular cavities on the capillary phenomena. Meanwhile, the effect of the cavity shape can be clearly explored in the other two experiments shown below.

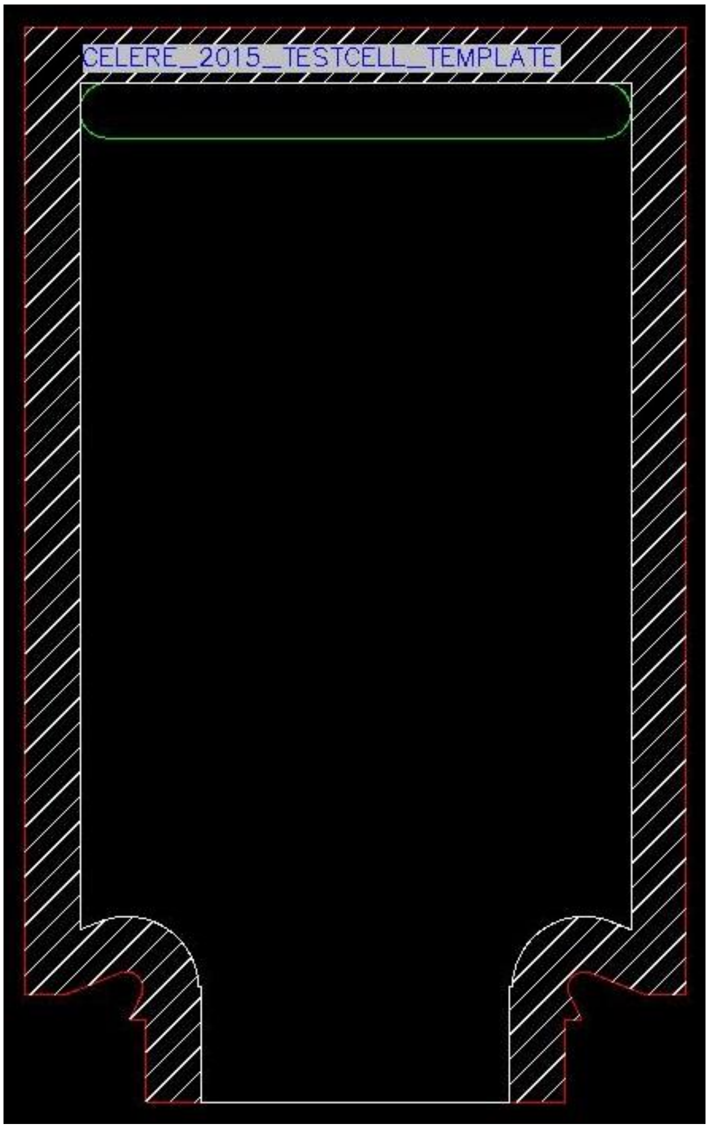




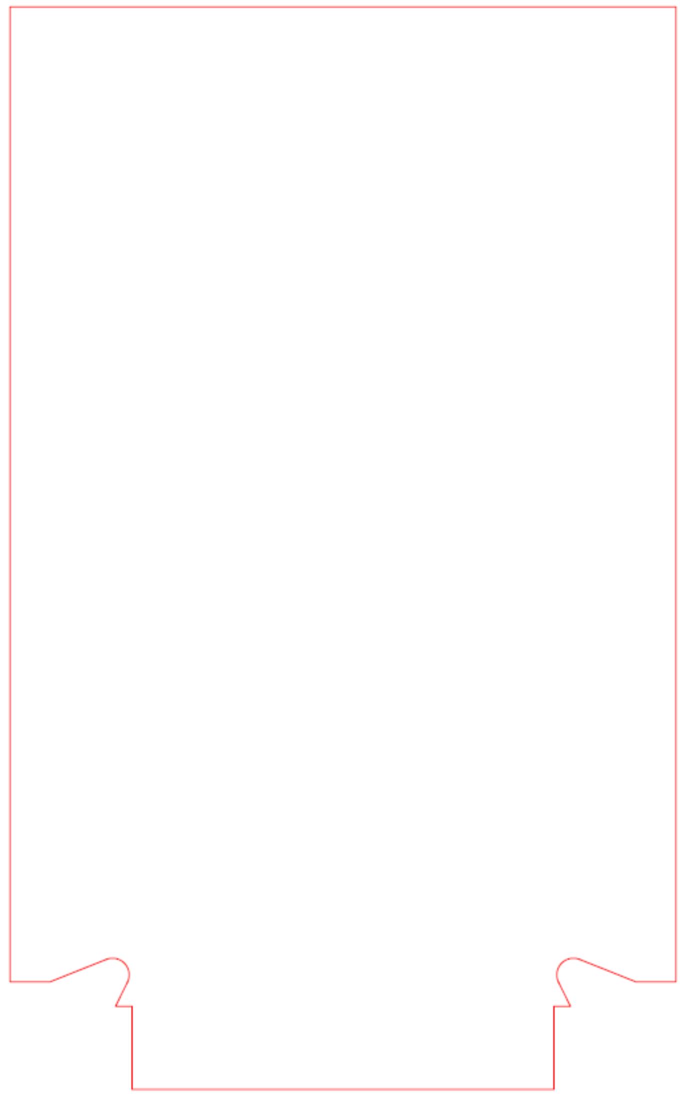
The two test cells shown to the right are examples of the use of 'islands,' i.e., where there are loose pieces cut from the middle layer that are used in the test cell. While this is an interesting area of study, much more work is required to prepare test cells when such features are included. **Therefore, test cells with 'islands' are prohibited.** Note that the merging of channels will result in one or more 'islands,' so channel merging is also prohibited.

Your Computer-Aided Design (CAD) drawing must be submitted so that it ready for use in fabricating the test cell with the computer-controlled laser cutter. Errors in the drawing may lead to rejection.

To ensure that the drawing is correctly prepared, it is helpful to imagine the laser cutter in operation. To cut a channel, the laser cutter must move upward from the bottom edge of the test cell, extend into the air gap location (marked in green), and then return back to the base of the test cell. To be clear, the channel cut must cross the green outline and not simply reach it. And the cuts must be continuous; i.e., there can be no gaps in the cut lines.





It is critical that the channels are vented by the air gaps at the top of the test cell. Otherwise, the trapped air will prevent the oil from rising in the channels during the experiment, although the shape of the meniscus will still change during the drop. Also note that the green line only shows the location of the air gaps which are in the front and back layers and not in the center layer which you are designing. As such, the green line is effectively virtual and cannot be part of the cut. The only automatic cuts in the middle layer are the outline, shown on the right above.

Although the channel cuts must cross into the air gap zone (outlined in green), they must not touch or cross into the border zone, marked with the diagonal pattern.

Channels must be at least 3 mm apart as very close spacing could allow the plastic to curl or break in handling. And of course, the cut lines must not cross each other or themselves.

There must be absolutely nothing outside the boundaries of the test cell when you have completed your drawing, including descriptive text, lines, etc.

Drawing and entry files must be named with the format:

CELERE_2018_<StateAbbrev>_<OrgAbbrev>_<AdvisorLastName>_<ParticipantAbbrev>

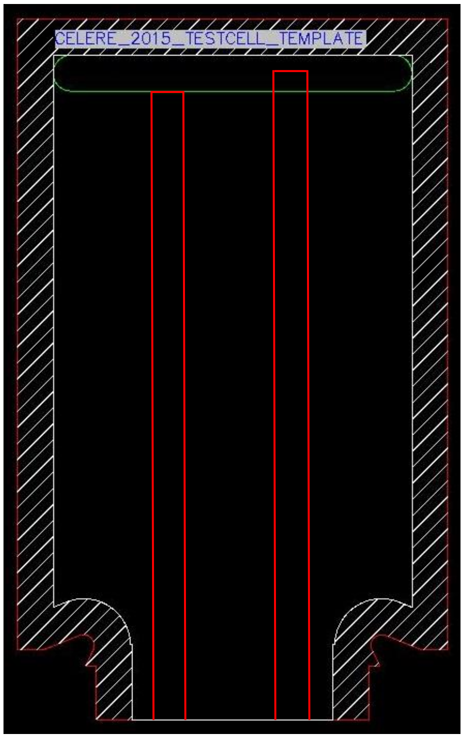
where the drawing files must be in the dwg format. The entry files should be pdf or doc files. As you might expect, your entry may not be selected if the files are unreadable.

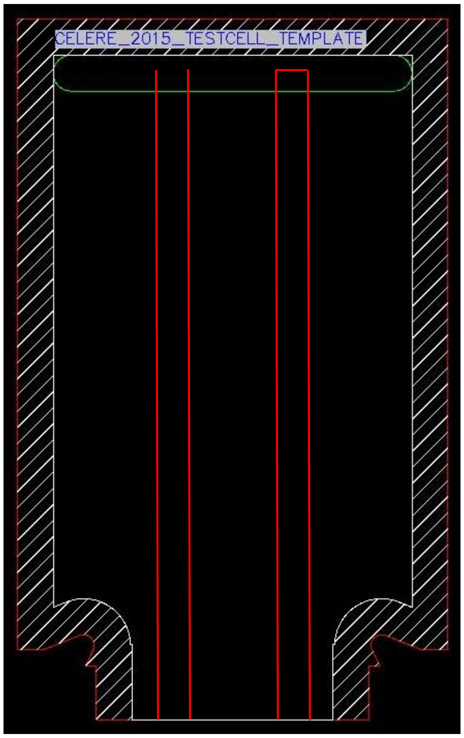
As an additional note, please weld the line segments together that you can.

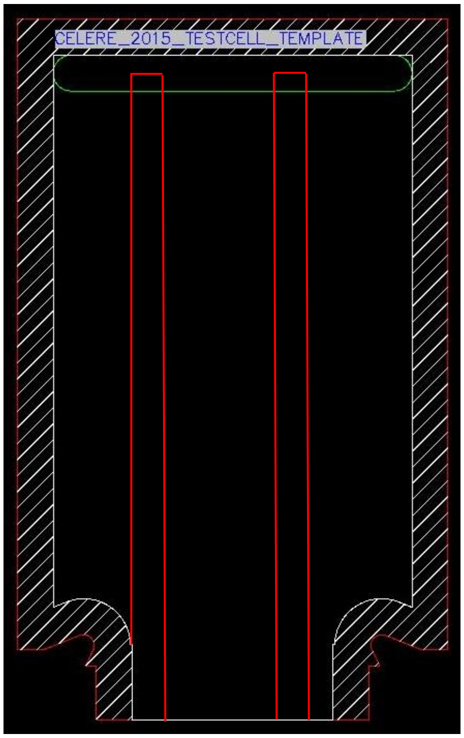
Common Mistakes

- Channels that don't extend into the green vent space
- Channels that have left and right sides which aren't connected at the top
- Channels which extend from the border zone instead of the test cell base
- Channels which touch the border zone (whether they extend to the test cell base or not)
- Channels which differ in more than way where the effects of the differences cannot be independently assessed,
- Drawings which have lines or text outside of the test cell borders
- Files in the wrong format, e.g., where entry forms must be in either a doc or pdf format.
- Files which are improperly named

The first four mistakes are illustrated in the figures below, where the left side of each figure shows the mistake and the right side shows a corrected version. All of these mistakes are violations of the design requirements and are grounds for rejection.







Design Challenge Suggestions

The CELERE Design Challenge is intended for open-ended, curiosity-driven research. There is no set CELERE challenge other than to design and submit an entry which follows the design requirements. However, participants are free to choose their own design challenge. Some suggestions include:

- Make the flow as bubbly as possible, i.e., where the bubbles are mixed with the oil and not just stuck in cavities.
- Make a 'fountain,' where the oil doesn't touch the left or right walls of the channel, rise as far as possible. To be clear, the oil rises because of its contact – and capillary action - with the front and back layers, so it really isn't unconfined. There are a few past examples of this type can be seen in the appendix.
- Make the oil rise as quickly as possible in a channel, for example, by variation of the inlet section.
- Advance what can be learned from past CELERE experiments by taking 'a next step.' For example, choose a past experiment that you find to be interesting and design a related experiment that can bring new understanding.
- Try something completely new!

Design Hints

FOCuS: Focus On Criteria for Selection

The most important hint should hopefully be obvious to all participants, but is nonetheless worth mentioning because of its critical importance. If you would like your experiment to be selected, then make sure to fulfill all of the design requirements, i.e., selection criteria. In the attack on the Death Star portrayed in *Star Wars IV: A New Hope*, the pilot Gold Five pilot tells Gold Leader to "Stay on target." Keep that quote and the design requirements close to mind when you are preparing your entry.

MOOD: Mainly Only One Difference

It is very important that the channels in your experiments vary in only one way! If you have two channels which differ in multiple ways, it will be very difficult to clearly determine how each difference affected the capillary motion. However with proper design, the effects of two differences (for example) can be independently assessed with three or more channels.

PEP: Past Effects the Present

The capillary motion in the upper part of a channel (i.e., the present) is affected by the channels' lower portion (i.e., the past). While features in a channel can change with height, the effect of the variation cannot be independently assessed with a single channel. For example, if you want to study the differing effects of square and circular cavities on the capillary motion, then they should be in separate channels. If they are both in the same channel, then the lower cavity will affect how the oil flows into the upper cavity. The dependence of the oil's flow on lower features should also be considered when designing comparison, e.g., control, channels, because it is often more important to match the bottoms of the channels rather than their tops.

ABS: Action effected by Both Sides

The capillary action is affected by both sides of each channel (as well as the front and back layers, but they are standard). While the left and right sides of a channel can be different, the effect of each side on the oil's motion cannot be independently assessed with a single channel. If you want to study the effect of two different channel sides, then they should be alone in two separate channels - but could be combined in a third channel.

KISS: Keep It Simple, Smarty!

The last three hints can be summarized by this simple but important phrase.

CELERE 2020?

It is anticipated that the CELERE design challenge will undergo some changes and may not be offered in the future, i.e., after 2019. However, NASA has begun offering annual problem-based Drop Tower Challenges in which teams of high school students design and build experimental hardware which is tested in NASA's 2.2 Second Drop Tower in Cleveland, Ohio. The challenge problem has changed from year to year, where the 2019 challenge is Plant Watering in Microgravity.

Questions

As a start, please review the CELERE information available on the web at:

http://spaceflightsystems.grc.nasa.gov/CELERE/
www.facebook.com/NASA.celere

For more information, please e-mail celere@lists.nasa.gov.

Appendix: Past CELERE Experiments

Past CELERE participants have been from across the United States, including states on both coasts. We've also had participation from a DODEA school in Germany for the children of U.S. military personnel! Thus far, most submissions have come from Ohio because of the word-of-mouth promotion by the CELERE staff who work at the NASA Glenn Research Center in Cleveland, Ohio.

State	City	Organization
California	El Cajon	Granite Hills High School
California	El Segundo	Da Vinci Communications High School
California	Ramon	California High School
California	San Diego	Canyon Crest Academy
California	San Diego	Carmel Valley Middle School
Colorado	Greenwood	Cherry Creek High School
Connecticut	Bethel	Bethel High School
Florida	St. Johns	Bartram Trail High School
Georgia	Columbus	Columbus High School
Georgia	Kennesaw	North Cobb High School
Illinois	Aurora	Illinois Mathematics and Science Academy
Indiana	Michigan City	Michigan City High School
Massachusetts	Boston	Boston Latin School
Massachusetts	Hyannis	Sturgis Charter Public School
Massachusetts	Lexington	Jonas Clarke Middle School
Michigan	Troy	Troy High School
Montana	Livingston	Park High School
Nevada	Henderson	Green Valley High School
New Hampshire	Bedford	Bedford High School
New York	Ava	Neighborhood After School Science Association (N.A.S.S.A.)
New York	Brooklyn	Bishop Kearney High School
New York	New York City	Bard High School Early College Manhattan
New York	New York City	Stuyvesant High School
New York	Rochester	Gates Chili Central School District
Ohio	Chesterland	West Geauga High School
Ohio	Cleveland	Villa Angela - St. Joseph High School
Ohio	Columbus	Bishop Watterson High School

Ohio	Dalton	Dalton Intermediate School
Ohio	Lakewood	St. Edward High School
Ohio	Medina	Broadway Creek Homeschool Academy
Ohio	Niles	Niles Middle School
Ohio	Toledo	St. John's Jesuit High School and Academy
Ohio	Toledo	St. Ursula Academy
Ohio	Wickliffe	Wickliffe High School
Oregon	Lake Oswego	Lake Oswego Junior High School
Pennsylvania	Holland	Council Rock High School South
Tennessee	Greeneville	Chicks in Space Science Club
Texas	Austin	Liberal Arts and Science Academy
Texas	Celeste	Celeste High School
Texas	Houston	Alief Early College High School
Texas	Houston	Village High School
Virginia	Chantilly	Westfield High School
Virginia	Fairfax	Thomas Jefferson High School for Science & Technology
Virginia	Herndon	Rachel Carson Middle School
Washington	Redmond	The Overlake School
Puerto Rico	Mayagüez	Centro Residencial de Oportunidades Educativas de Mayagüez (CROEM)
Germany	Kasierslautern	Kasierslautern High School (which is a DODEA school)

Selected experiments are depicted and briefly described on the following pages. The experiments are generally shown at approximately halfway through the drop test (i.e., approximately 1 second after the release), where up is to the left and down is to the right. The position of the oil can be seen by the curved meniscus (i.e., liquid-gas interface) which is visible in each channel. The experiments are nominally organized by the general nature of their study, i.e., where they investigated the following effects on the capillary motion.

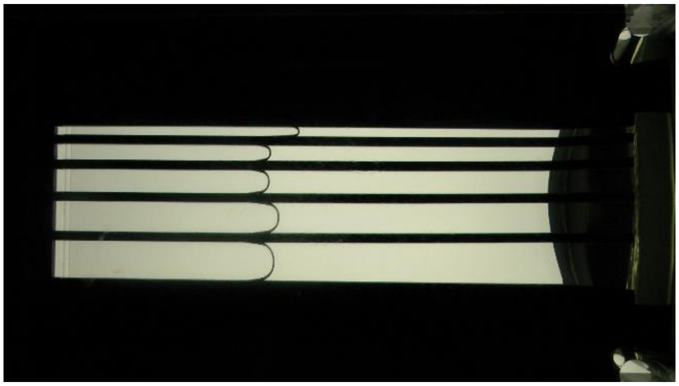
1. Channel width (submission of this type are now discouraged)
2. Channel path
3. Channel entry
4. Uniform expansion and contraction
5. Abrupt expansion and contraction
6. Cavities and protrusions
7. Channel roughness
8. Branching
9. Miscellaneous
10. Combined effects (submission of this type are generally discouraged)

Most of the experiments that are not included in this review are from 2013 when the design challenge was pilot tested on an invitational basis. During that phase, there wasn't a requirement for two or more channels and some experiments were submitted with a single channel. Those test cell designs don't meet the current CELERE requirements and were excluded from this guide for brevity. Likewise, past experiments featuring 'islands' are also excluded from this review, where they were not prohibited until 2016.

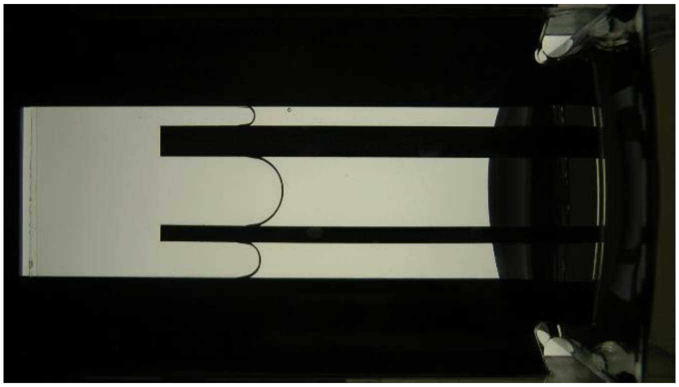
The results of some past experiments can be viewed on the Videos page of the program's website, http://spaceflightsystems.grc.nasa.gov/CELERE/. But all of the data from past experiments are available at http://celere.mme.pdx.edu/. Note that the video files are not standard, but can be viewed (for example) using *VLC Media Player*, which can be freely downloaded from http://www.videolan.org/vlc/index.html.

1. Effects of the Channel Width

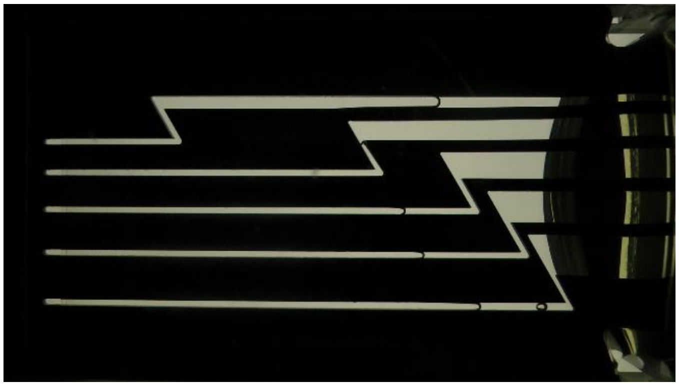
The three following experiments examined the effects of the channel width on the capillary action in vertical straight-walled channels. **Students are discouraged from submitting additional experiments of this type, because the effect of the channel width can be assessed from the results of these past experiments!** *Note that up is to the left in these images, and down is to the right (i.e., where the cameras was on its side).*



This 2013 experiment from St. Ursula Academy (Toldeo, OH) compared the capillary action in channels with five different widths, where the width was the only difference between the channels.



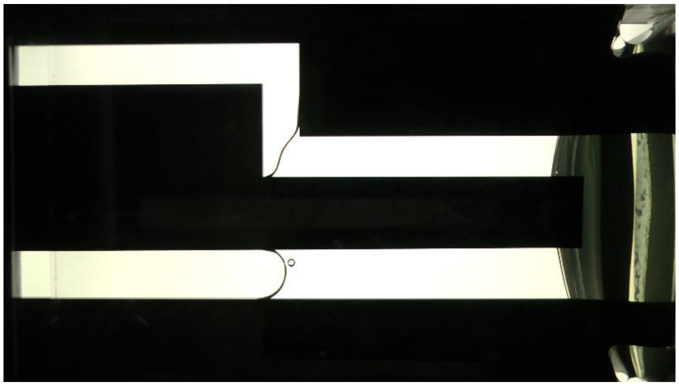
This 2013 experiment from St. Ursula Academy (Toldeo, OH) compared the capillary action in channels with three different widths.



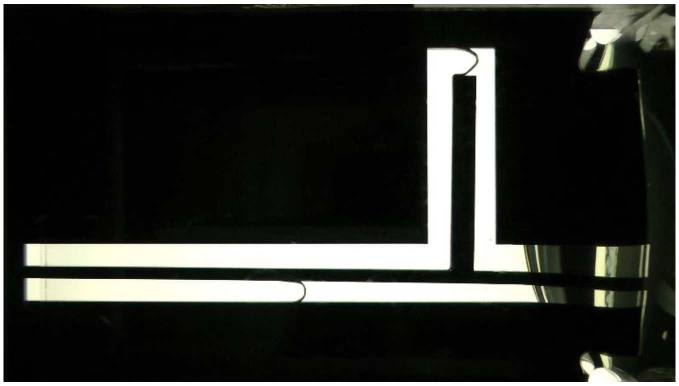
This 2013 experiment from Park High School (Livingston, MT) compared the capillary action in channels with five different widths. The fluid motion was assessed in part by having an identical volume in each of the channels - up to the abrupt contraction to the narrow bent portion.

2. Effects of the Channel Path

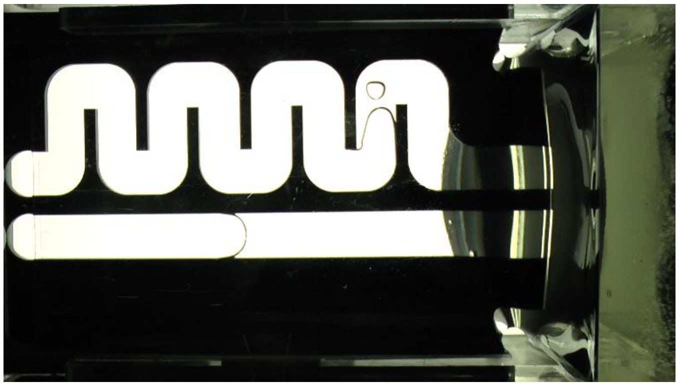
Note that up is to the left in these images, and down is to the right (i.e., where the cameras was on its side).



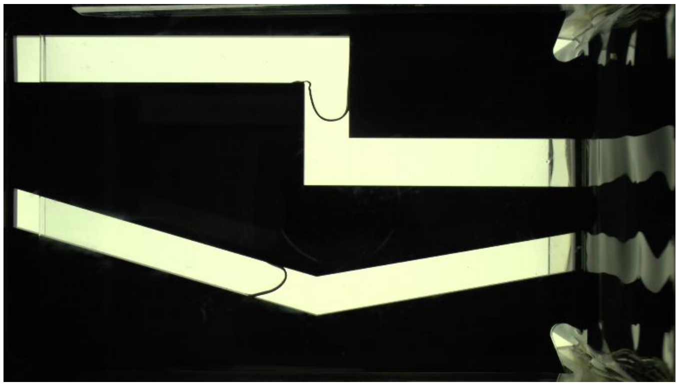
This 2014 experiment from St. Edward High School (Lakewood, OH) investigated the effect of a single orthogonal offset in the vertical channel.



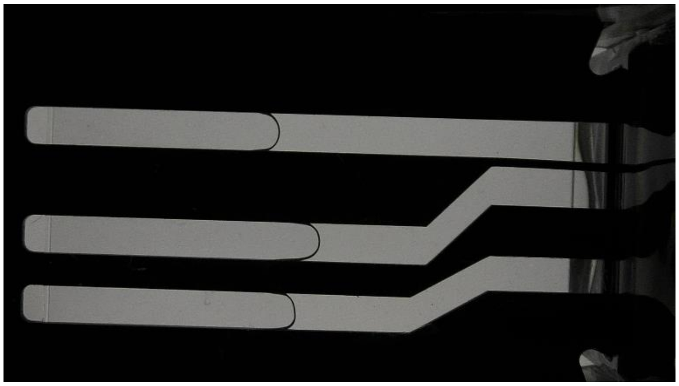
This 2014 experiment from St. Ursula Academy (Toldeo, OH) studied the effect of a single orthogonal back-and-forth shift in the otherwise vertical channel.



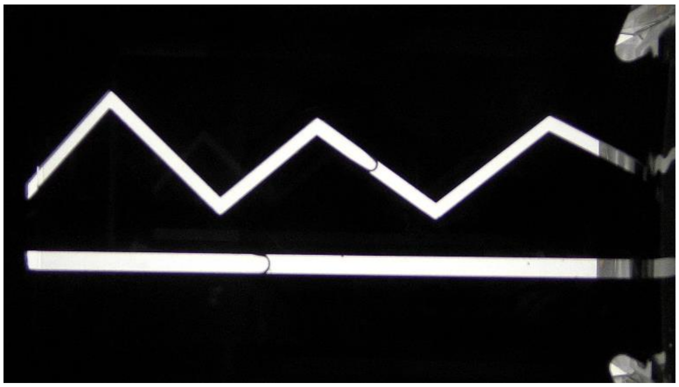
This 2014 experiment from St. Ursula Academy (Toldeo, OH) examined the effect of a back-and-forth orthogonal path (with rounded outer corners) on the capillary action.



This 2015 experiment from St. Ursula Academy (Toldeo, OH) investigated the effect of turn angle on the capillary motion of the oil.

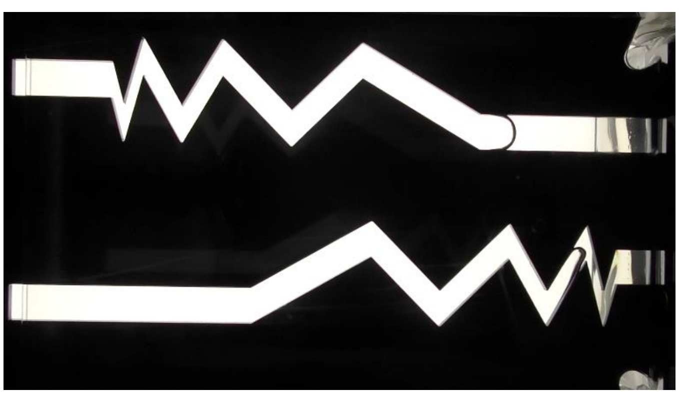


This 2017 experiment from the Gates Chili Central School District (Rochester, NY) examined the effect of angled bends in the channel on the rise of the silicone oil.

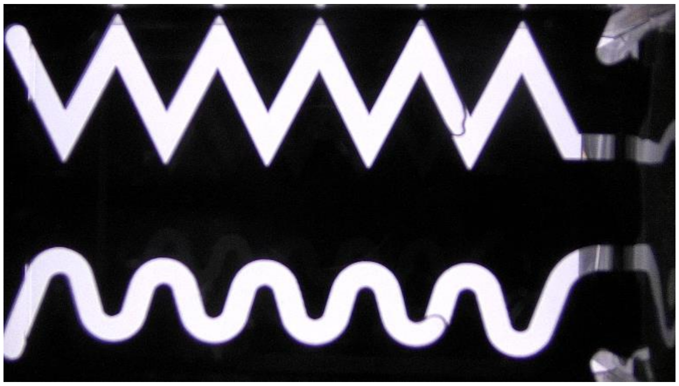


This 2017 experiment from the Chicks in Space Science Club (Greeneville, TN) explored the effect of a zig-zags on the motion of the silicone oil.

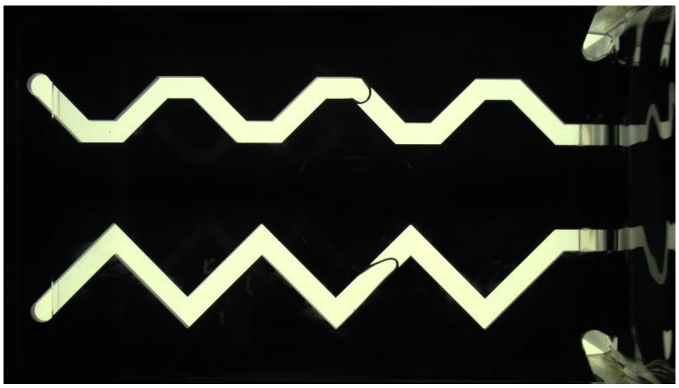
This 2018 experiment from the North Cobb High School (Kennesaw, GA) studied the effects of the zig-zag angles on the oil's motion.



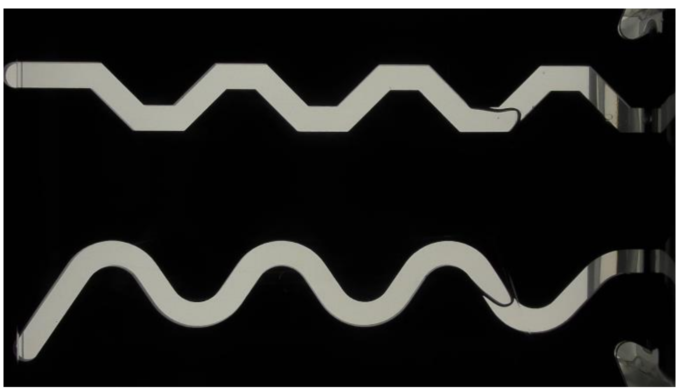
This 2018 experiment from Westfield High School (Chantilly, VA) examines the effect of the zigzagging channel on the capillary motion, where the two channels are the same but inverted relative to the other.



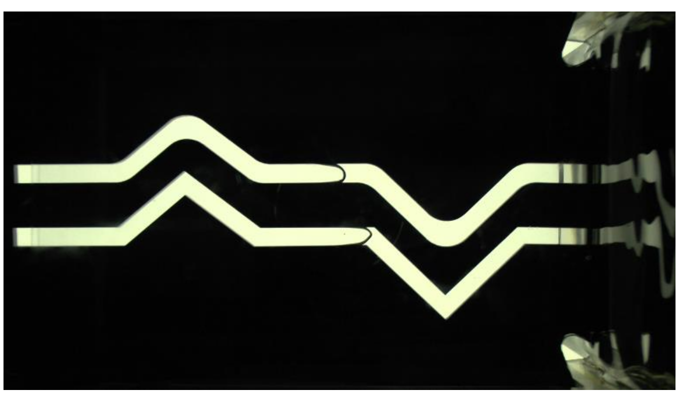
This 2017 experiment from the Celeste High School (Celeste, TX) examined the effect of rounded vs. sharp turns in zigzagging channels.



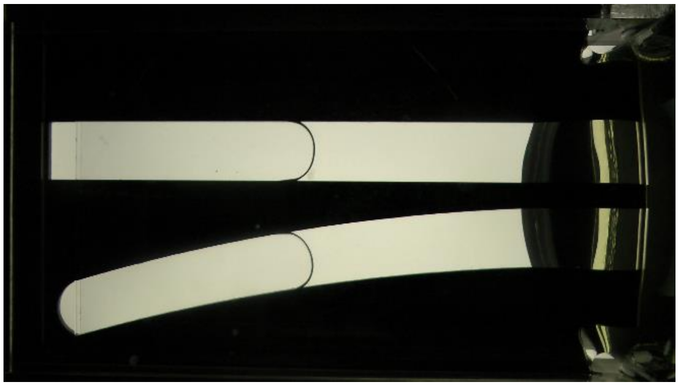
This 2015 experiment from Columbus High School (Columbus, GA) studied the effects of truncated turns on the capillary flow in a zigzagging channel.



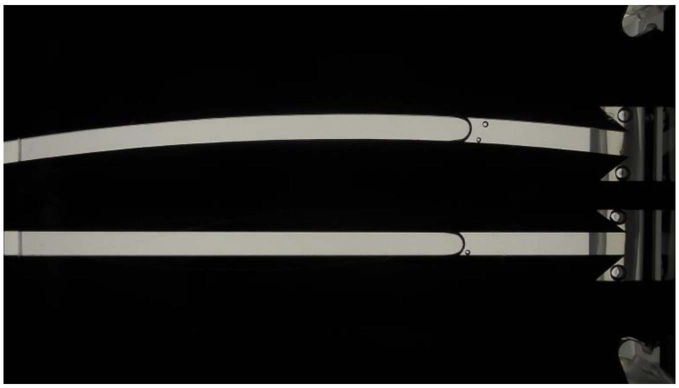
This 2018 experiment from the Village High School (Houston, TX) is similar to the preceding experiment but has a smoothly undulating channel instead of the zigzagging channel.



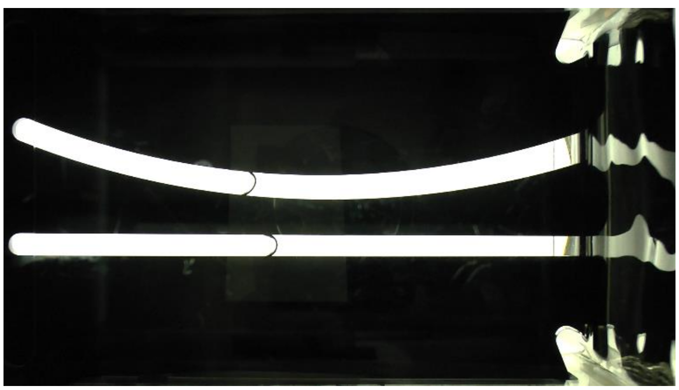
This 2015 experiment from St. Ursula Academy (Toldeo, OH) examined the effect of rounded and sharp corners on the capillary flow through a diagonally shifting path.



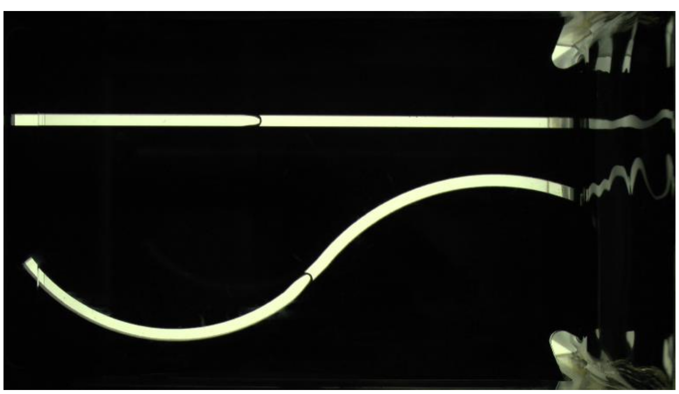
This 2013 experiment from Columbus High School (Columbus, GA) studied the effect of channel curvature on the capillary motion.



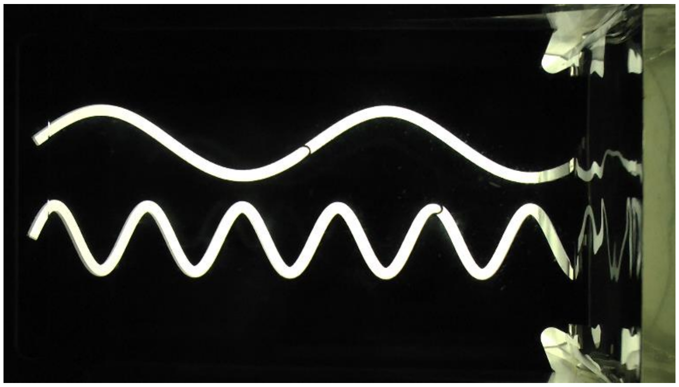
This 2018 experiment from the Boston Latin School (Boston, MA) examined the effect of a curved path on the oil's rise, where the inlet section in each channel had an abrupt contraction.



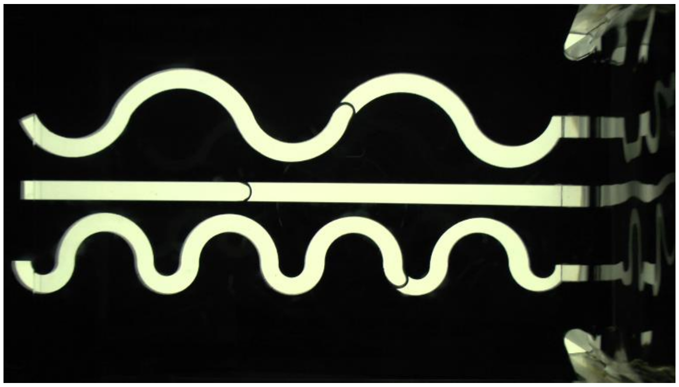
This 2015 experiment from St. Ursula Academy (Toldeo, OH) investigated the effect of a simple curved path on the capillary action.



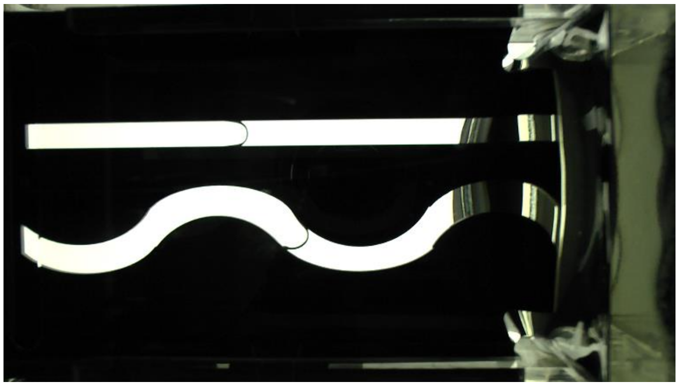
This 2015 experiment from St. Ursula Academy (Toldeo, OH) studied the effect of a curving path with two turns on the capillary action.



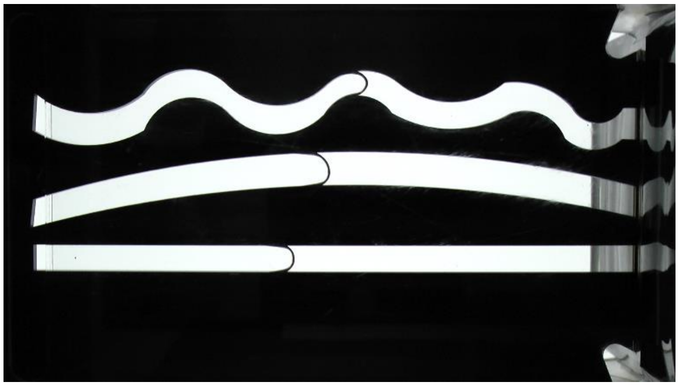
This 2015 experiment from the Illinois Mathematics and Science Academy (Aurora, Illinois) investigated the effect of a curving path's wavelength on the capillary action.



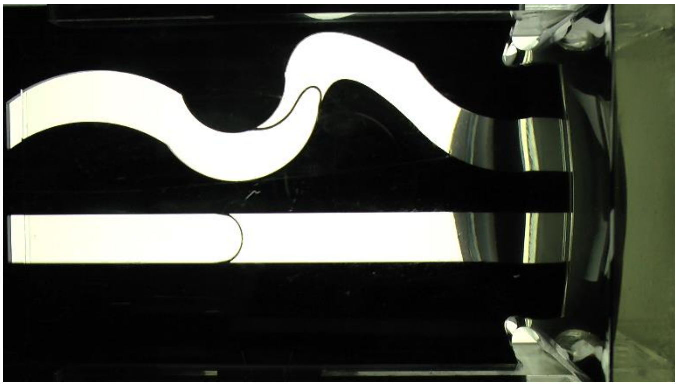
This 2015 experiment from St. Ursula Academy (Toldeo, OH) is similar to the previous experiment, where it again examined the effect of a curving path's wavelength on the capillary action. However, these channels turn a full 180 degrees while the channels in the previous experiment turn at smaller angles in a nominally zigzag pattern.



This 2014 experiment from St. Ursula Academy (Toldeo, OH) investigated the effect of a (generally regular) curving path on the capillary action.



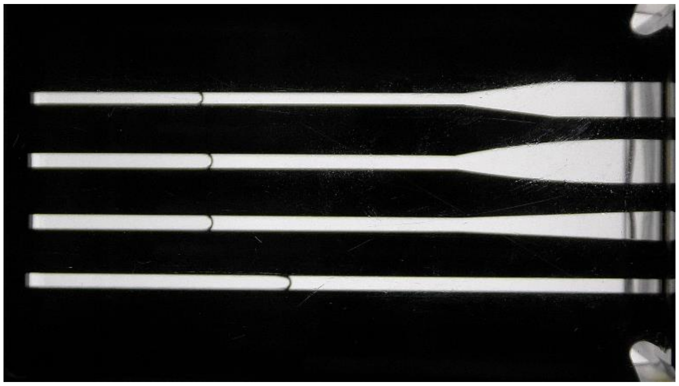
This 2016 experiment from the Granite Hills High School (El Cajon, CA) is similar to the preceding entry with its (generally regular) winding path, but also adds a simple curved path.



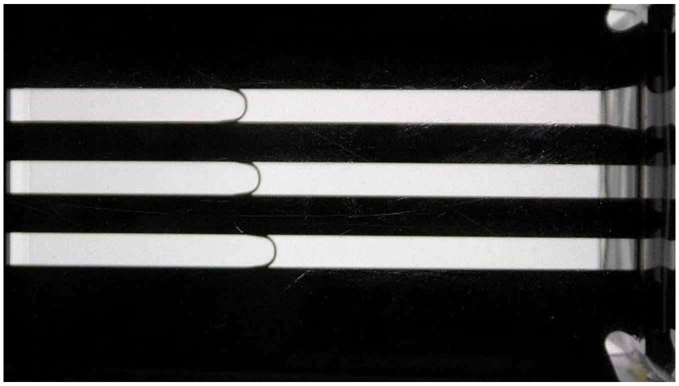
This 2014 experiment from St. Ursula Academy (Toldeo, OH) studied the effect of an irregular curving path on the capillary action.

3. Effects of the Channel Inlet

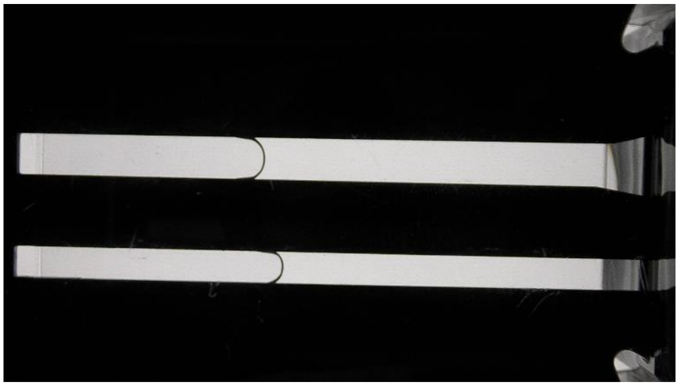
Note that up is to the left in these images, and down is to the right (i.e., where the cameras was on its side).



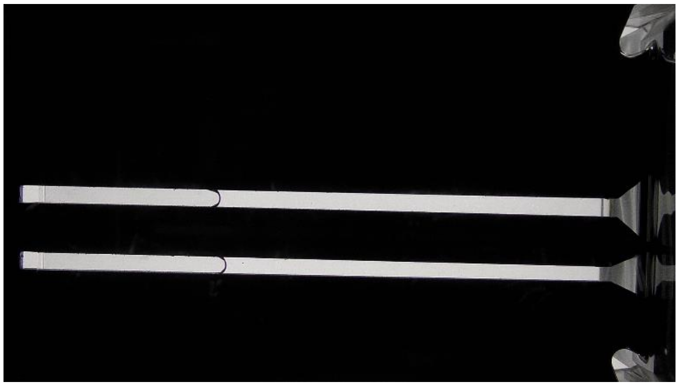
This 2016 experiment from Bedford High School (Bedford, NH) investigates the effect of various contractions on the capillary rise of the oil.



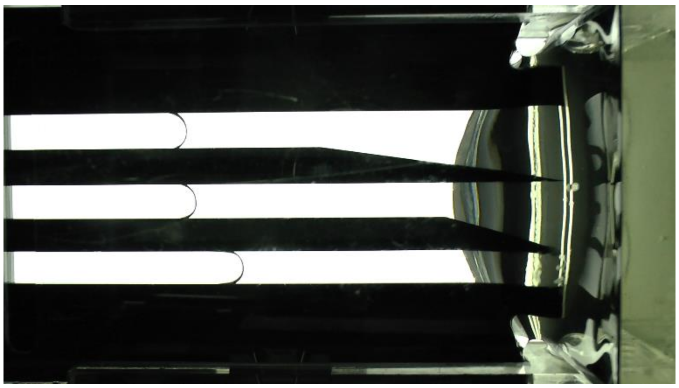
While it is difficult to see from this image, this 2016 entry from Bethel High School (Bethel, CT) examines the influence of uniformly narrowing inlet sections of different sizes on the capillary motion. However, the test cell drawing for this and the rest of the experiments can be found online with all of the associated results at http://celere.mme.pdx.edu/.



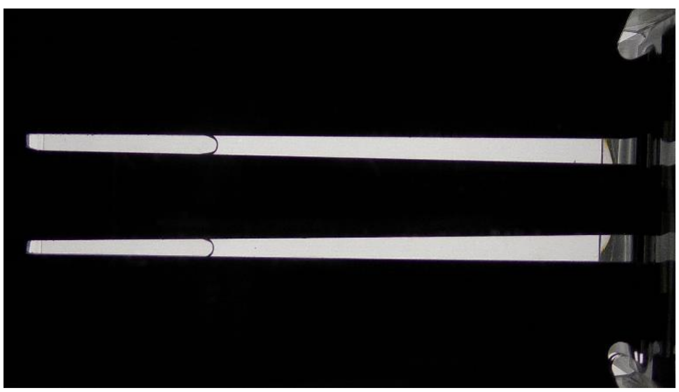
Similar to the preceding experiment, this 2017 experiment from St. Ursula Academy (Toldeo, OH) examined the effect of a narrowing inlet section on the capillary rise of the silicone oil.



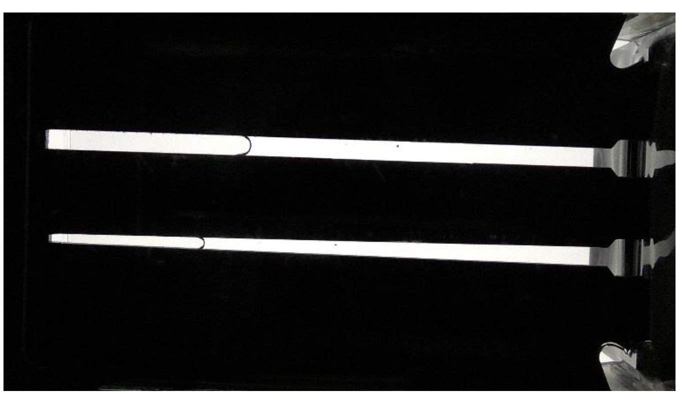
This 2017 experiment from St. Ursula Academy (Toldeo, OH) investigated the effect of triangular inlet sections on the rise of the silicone oil.



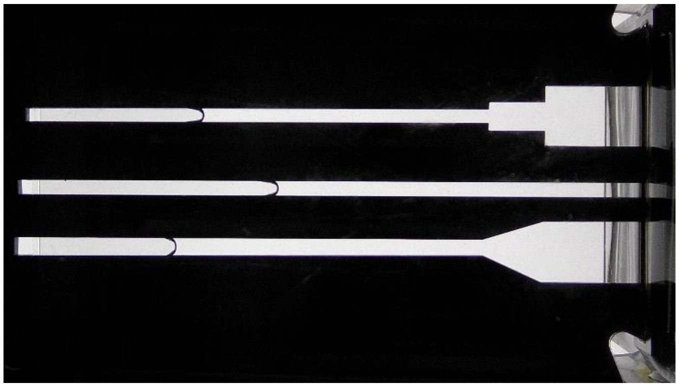
This 2014 experiment from St. Ursula Academy (Toldeo, OH) compared the capillary motion in a straight channel with two channels with uniformly narrowing entry sections of different sizes. It is similar to the previous experiment, but the contraction is only on the left (bottom) side of the channel.



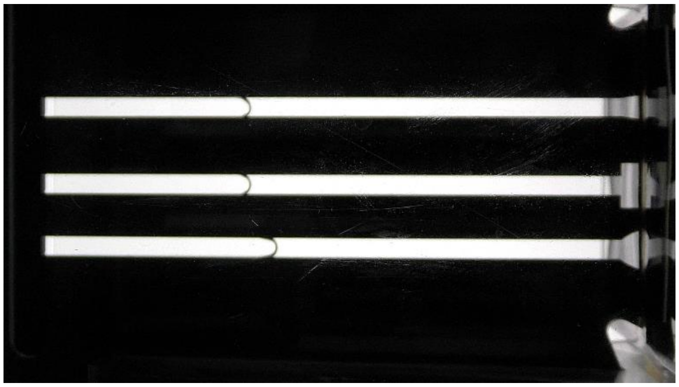
While it is very difficult to see from this image, this 2017 experiment from St. Ursula Academy (Toldeo, OH) examined the effect of the curvature at the channel inlet on the capillary motion of the silicone oil.



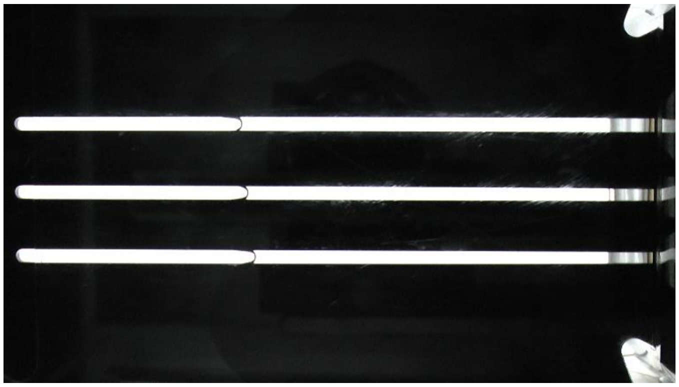
While it is difficult to see from this image, this 2017 experiment from St. Ursula Academy (Toldeo, OH) investigated the effect of the channel inlet on the rise of the silicone oil in the two channels.



This 2016 entry from the Michigan City High School (Michigan City, IN) examines the effect of various inlets on the capillary motion.



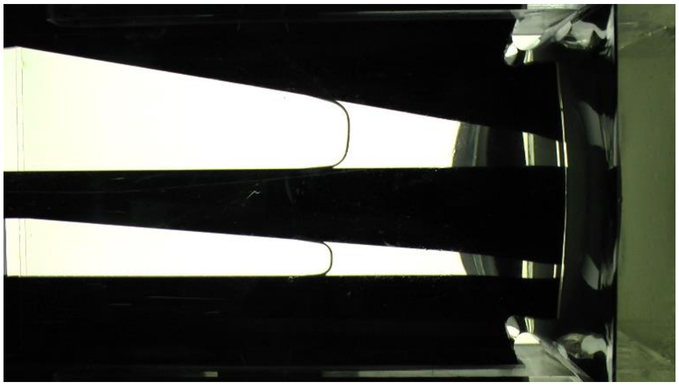
Similar to the previous experiment, this 2016 experiment from Troy High School (Troy, MI) examines the effect of various inlets on the capillary motion … where the results are similar.



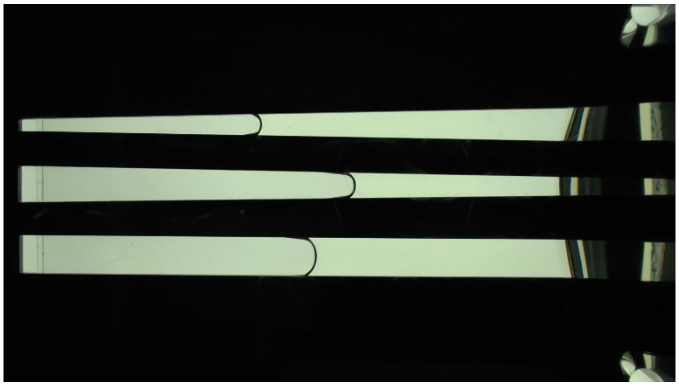
While it very difficult to see from this image, this 2016 experiment from the Liberal Arts and Science Academy (Austin, TX) also examines the effect of inlet sections of different shapes on the rise of the oil. Again, the test cell drawing for this and the rest of the experiments can be found online with all of the associated results at http://celere.mme.pdx.edu/.

4. Effects of Uniform Expansion and Contraction

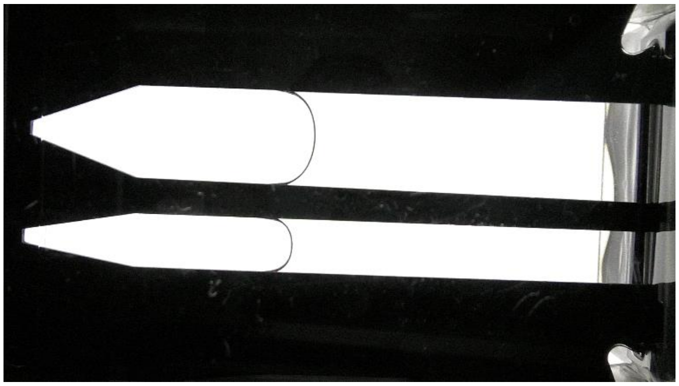
Note that up is to the left in these images, and down is to the right (i.e., where the cameras was on its side).



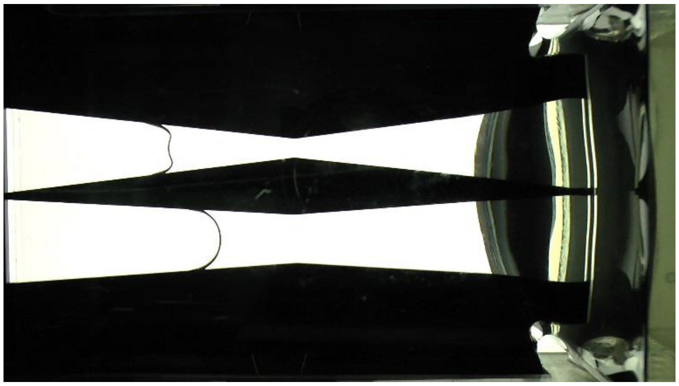
This 2014 experiment from St. Ursula Academy (Toldeo, OH) compared the capillary motion in two uniformly-widening wedge-shaped channels, where one side is vertical and other is angled (where the angle was varied between the two channels).



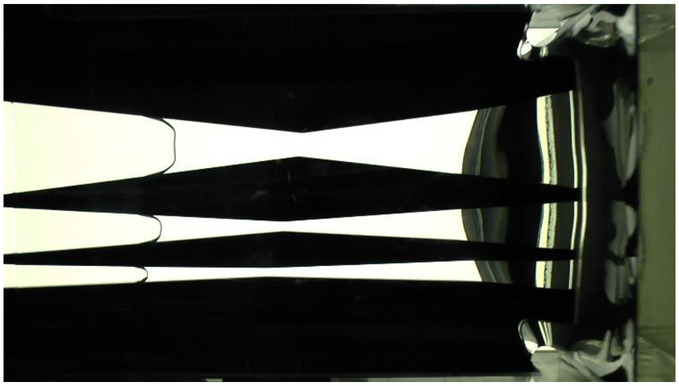
This 2014 experiment from St. Ursula Academy (Toldeo, OH) compared the capillary motion in straight, uniformly expanding, and uniformly narrowing channels.



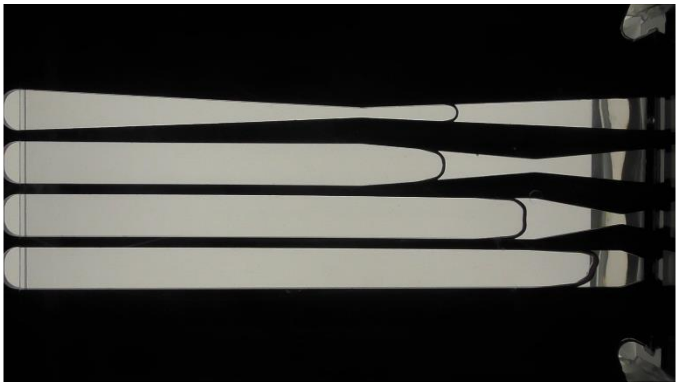
This 2017 experiment from St. Ursula Academy (Toldeo, OH) examined the effect of the contraction angle on the capillary action, although for much of the drop the effect of the channel width was revealed.



This 2014 experiment from St. Ursula Academy (Toldeo, OH) investigated the size effect on the capillary motion through an hourglass-shaped contraction and expansion.



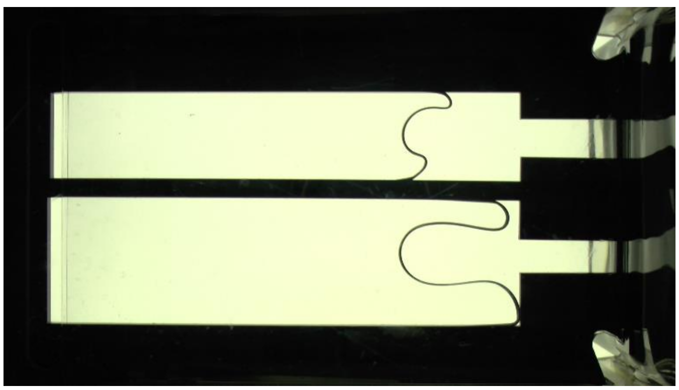
Like the preceding experiment, this 2014 experiment from St. Ursula Academy (Toldeo, OH) studied the size effect on the capillary motion through an hourglass-shaped contraction and expansion.



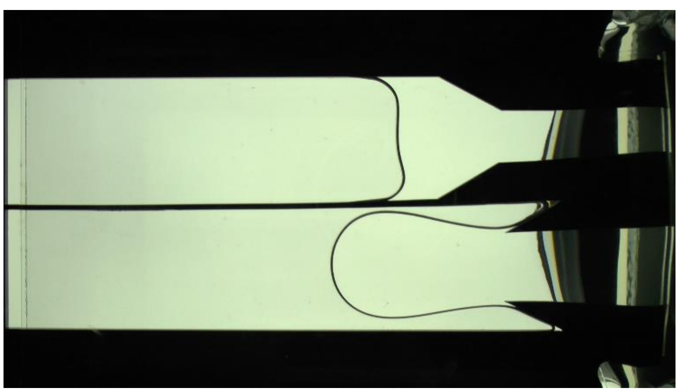
This 2018 experiment from Cherry Creek High School (Greenwood, CO) examined the effect of the length of the hourglass-shaped contraction and expansion on the capillary action.

5. Effects of Abrupt Expansion and Contraction

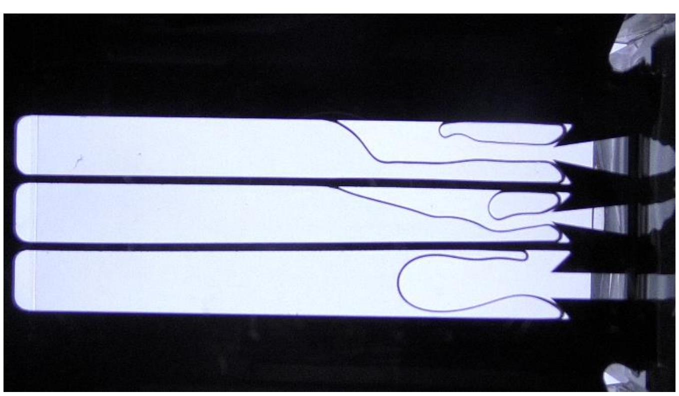
Note that up is to the left in these images, and down is to the right (i.e., where the cameras was on its side).



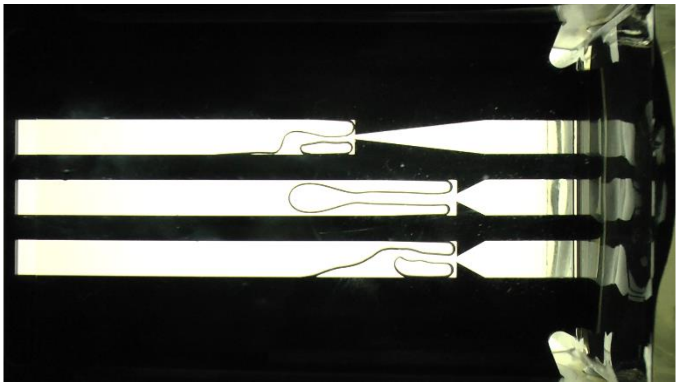
This 2015 experiment from St. Ursula Academy (Toldeo, OH) investigated the effect of the width of an abrupt expansion on the capillary motion.



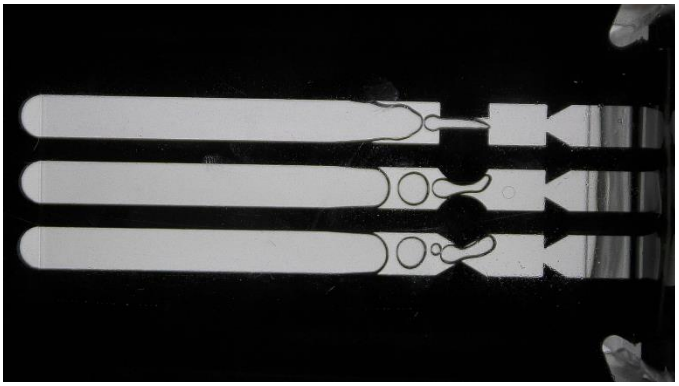
This 2014 test cell from St. Ursula Academy (Toldeo, OH) compares the effect of an abrupt expansion with a uniform expansion to a larger channel width.



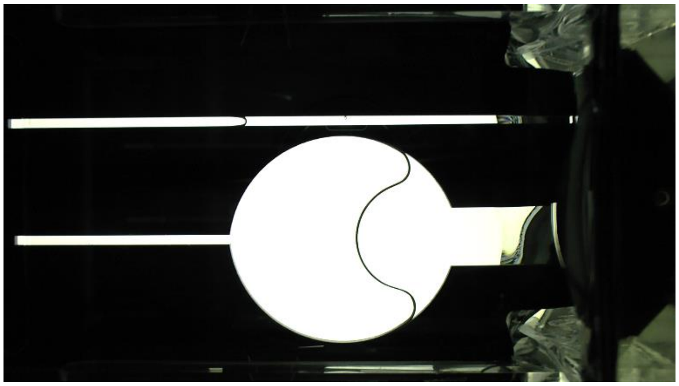
This 2017 experiment from the Liberal Arts and Science Academy (Austin, TX) examined the effect of the contraction leading into an abrupt expansion on the silicone oil's motion.



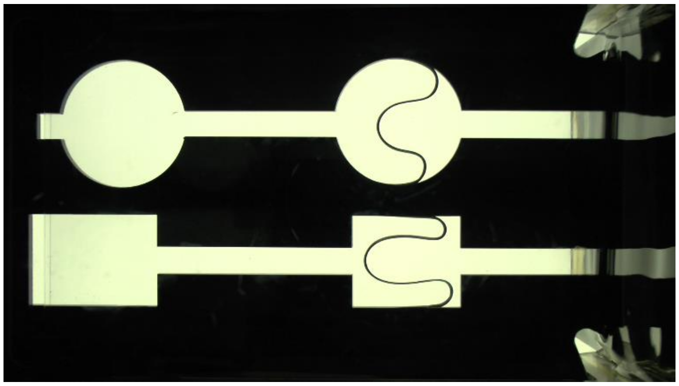
This 2015 experiment from the Illinois Mathematics and Science Academy (Aurora, Illinois) investigated the effect of both the gap size (via the leftmost channels shown at the bottom) and the contraction length (via a comparison of the leftmost and rightmost channels) on the oil's motion.



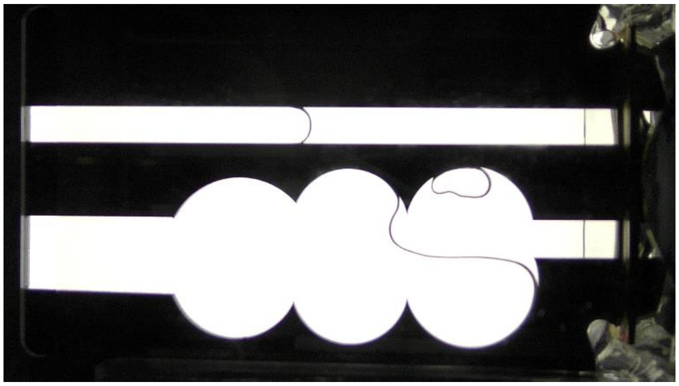
This 2017 experiments from the Broadway Creek Homeschool Academy (Medina, OH) examined the effect of different throat geometries on the motion of the silicone oil.



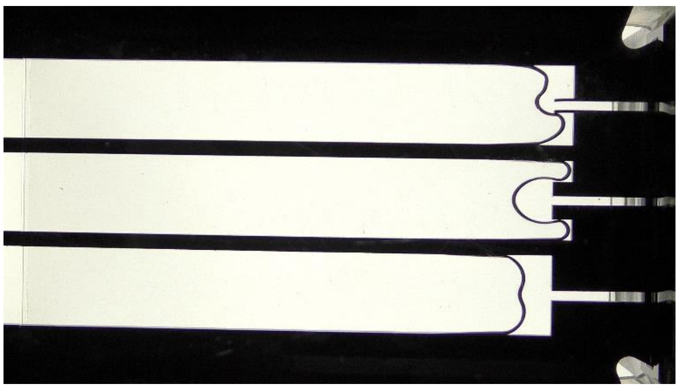
This 2014 experiment from St. Ursula Academy (Toldeo, OH) examined the effect of an abrupt (circular) expansion on the capillary motion.



This 2015 experiment from Columbus High School (Columbus, GA) investigates the effect of the abrupt expansion's shape on the oil's motion.



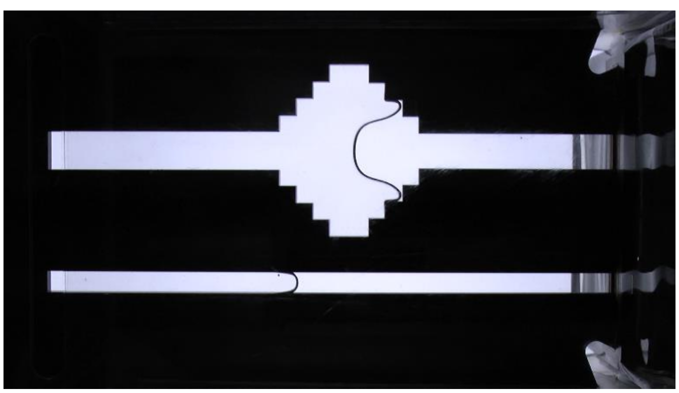
This 2016 experiment from Bishop Kearney High School (Brooklyn, NY) investigates the effect of an abrupt expansion into a complex shape on the motion of the oil.



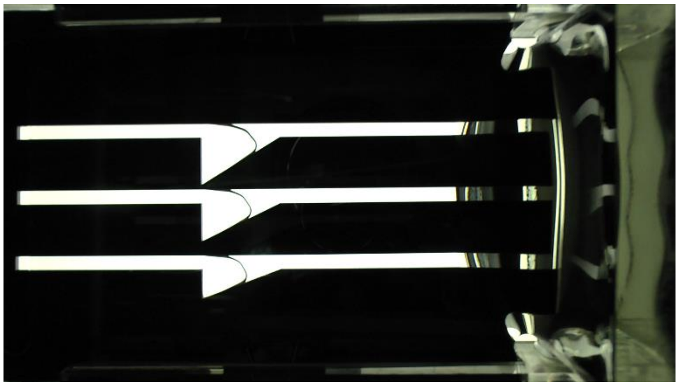
This 2016 experiment from Kasierslautern High School (a DODEA school in Kasierslautern, Germany) examined the effects of having the channel extend into the wide section.

6. Effects of Cavities and Protrusions

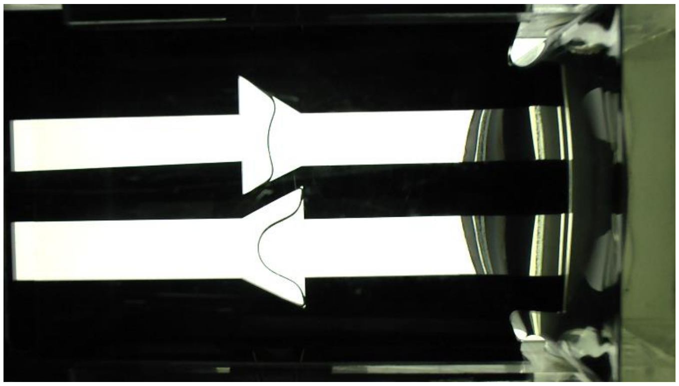
Note that up is to the left in these images, and down is to the right (i.e., where the cameras was on its side).



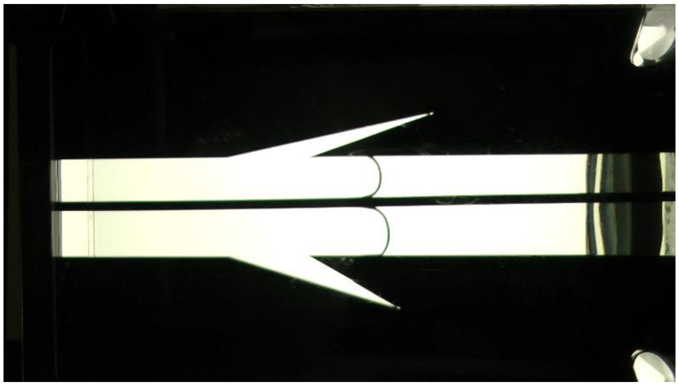
This 2016 experiment from Wickliffe High School (Wickliffe, OH) examined the effect of a stepped cavity on the capillary flow.



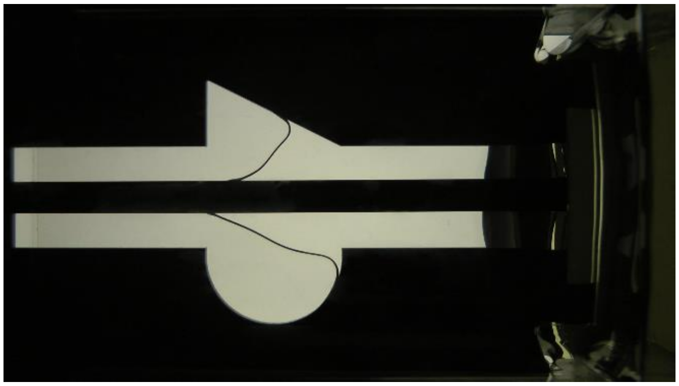
This 2014 experiment from St. Ursula Academy (Toldeo, OH) compared the capillary flow in channels with triangular cavities of different sizes.



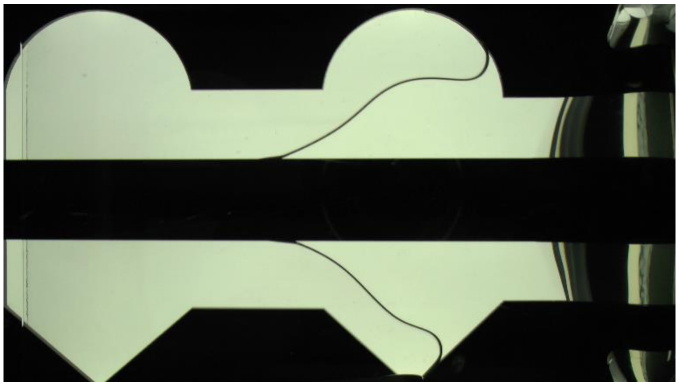
This 2014 experiment from St. Ursula Academy (Toldeo, OH) examined the effect of a triangular cavity's vertical orientation on the capillary motion.



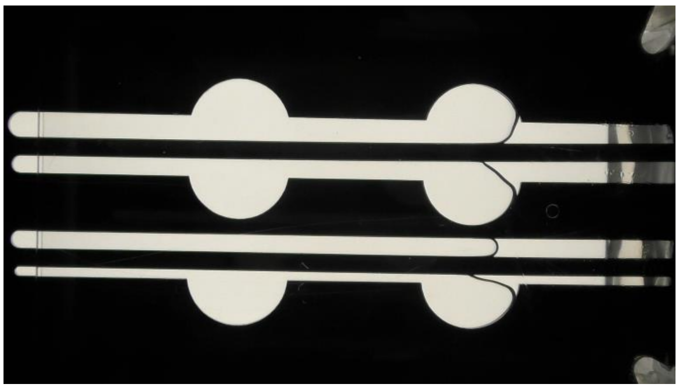
This 2014 experiment from St. Edward High School (Lakewood, OH) investigated the effect of different downward-facing triangular cavities on the capillary flow.



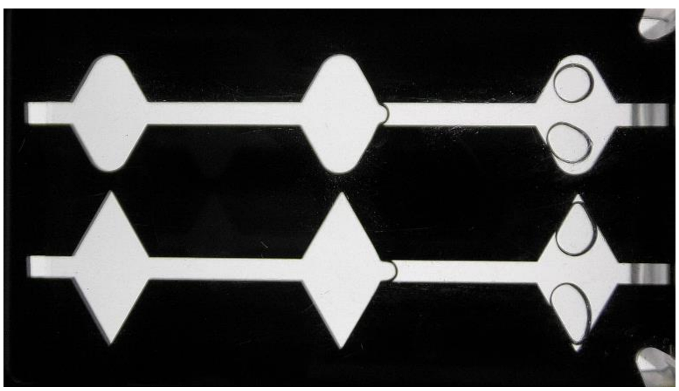
This 2013 experiment from St. Ursula Academy (Toldeo, OH) examined the differences between triangular and semicircular cavities on the upward capillary flow.



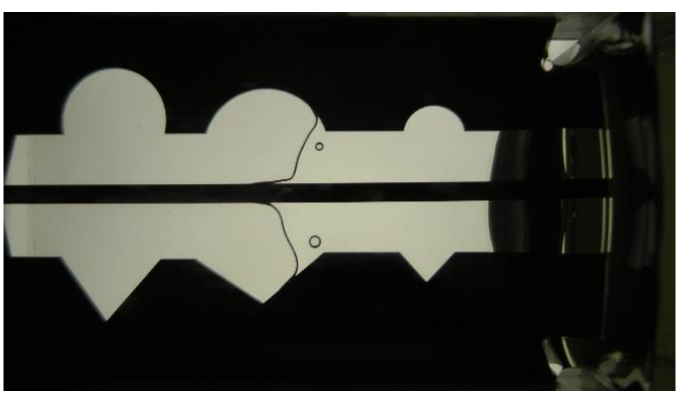
Like the preceding experiment, this 2014 experiment from St. Edward High School (Lakewood, OH) investigated the effect of triangular and semicircular cavities on the upward capillary flow.



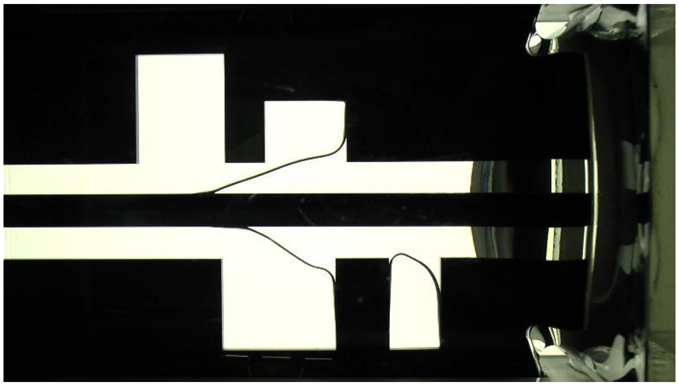
This 2018 experiment from West Geauga High School (Chesterland, OH) studied the rise of the oil with hemispherical cavities protruding from channels of different widths.



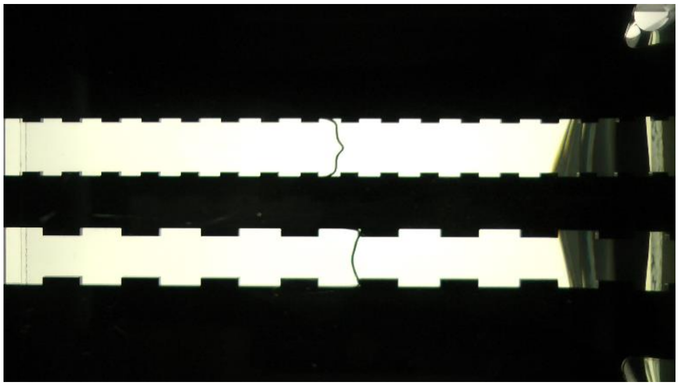
This 2016 experiment from Sturgis Public Charter School (Hyannis, MA) examines the effect of rounded vs. sharp corners in the repeating symmetric cavities.



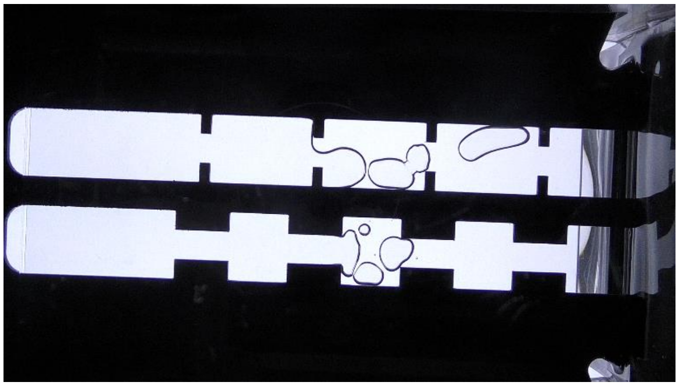
This 2013 experiment from St. Ursula Academy (Toldeo, OH) also explored the effect of triangular and semicircular cavities, but with cavities of increasing size with channel height.



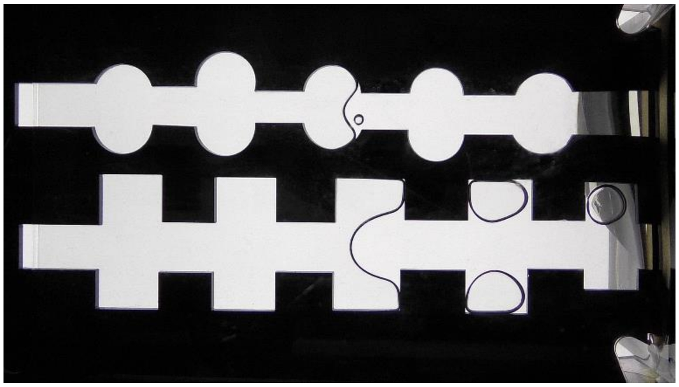
This 2014 experiment from St. Ursula Academy (Toldeo, OH) is similar to the previous one, but explored the effect of rectangular cavities, where the cavities grew (with channel height) in the left channel (i.e. on the bottom in the image above) and in width in the right channel.



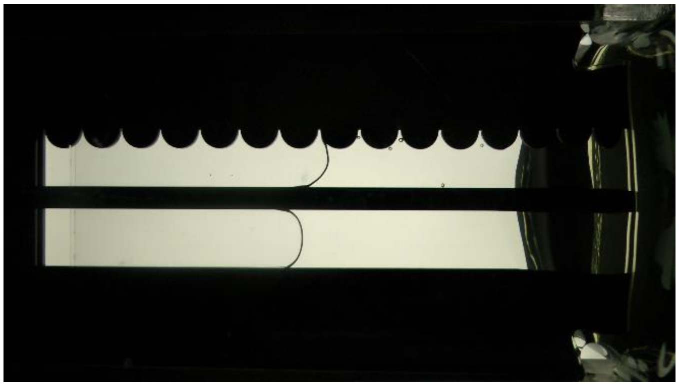
This 2014 experiment from St. Edward High School (Lakewood, OH) evaluates the effect of size of repeating rectangular cavities on the capillary motion.



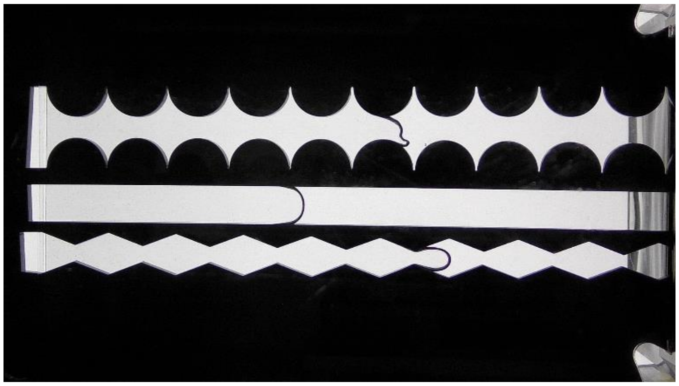
This 2017 experiment from the Liberal Arts and Science Academy (Austin, TX) examined the effect of cavity size on the capillary rise of the silicone oil.



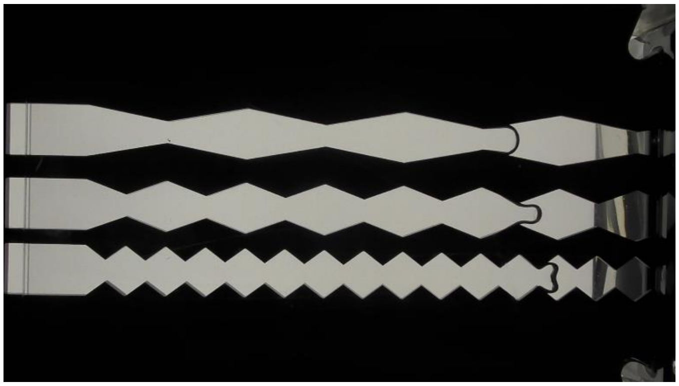
This 2016 experiment from the Alief Early College High School (Houston, TX) evaluates the effects of repeating cavities on the capillary motion.



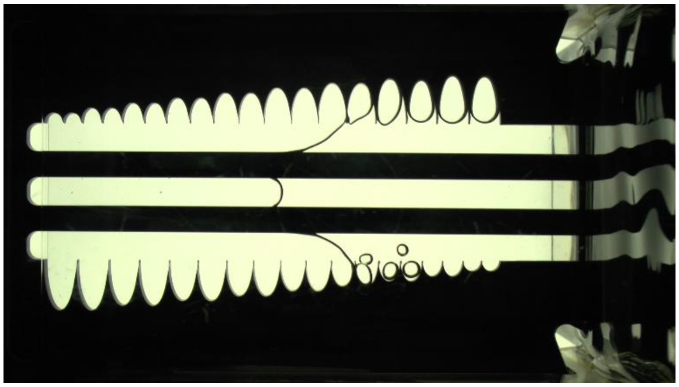
This 2013 experiment from Columbus High School (Columbus, GA) examined the effect of a scalloped channel wall on the capillary motion.



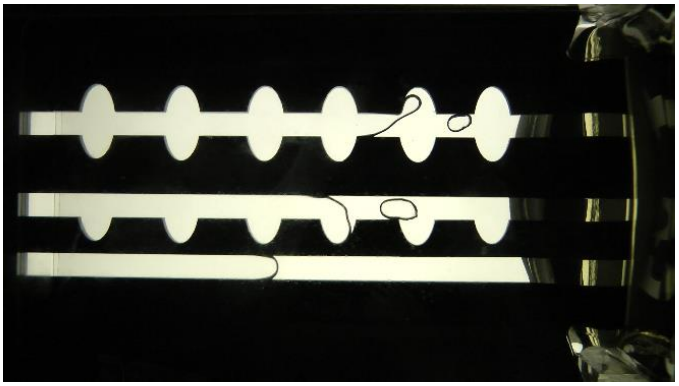
This 2016 experiment from the Michigan City High School (Michigan City, IN) examines the effects of both scalloped and zigzagging channel walls.



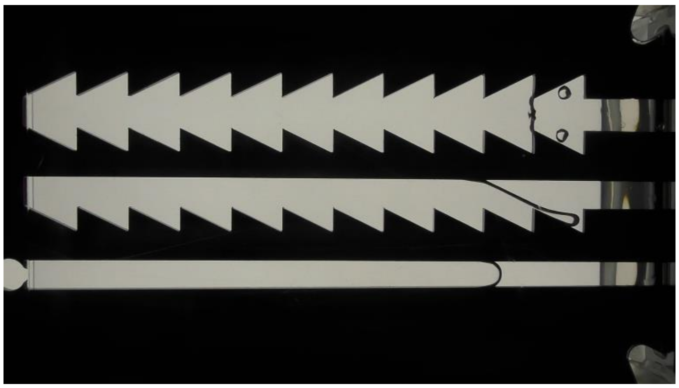
This 2018 experiment from Gates Chili High School (Rochester, NY) investigated the effect of repeating zig-zagging walls on the rise of the silicone oil.



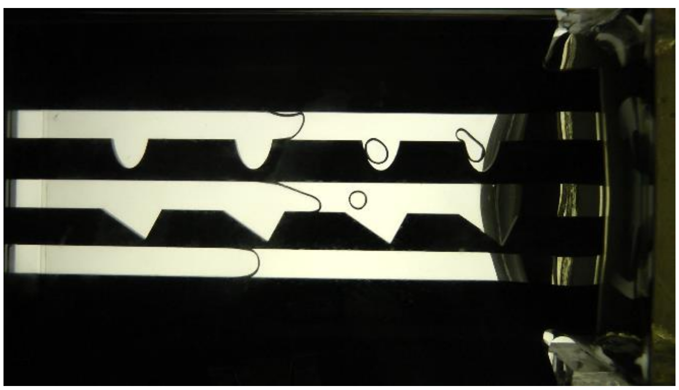
This 2015 experiment from Bishop Watterson High School (Columbus, OH) explored the effect of repeating ellipsoidal cavities on the capillary motion, where the cavities increase or decrease in depth with channel height.



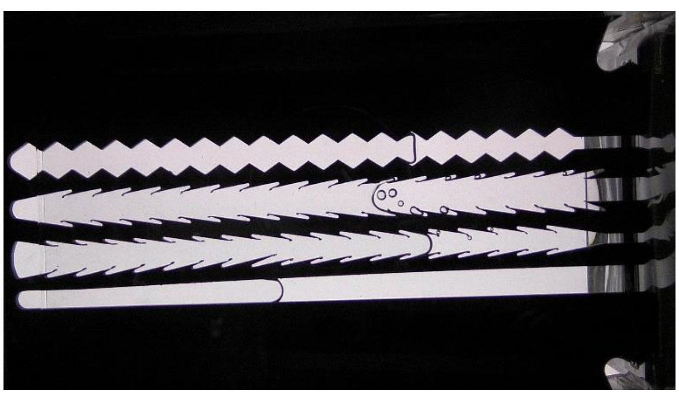
This 2013 experiment from the Niles Middle School (Niles, OH) examines the effect of repeated elliptical cavities on one, both, or no sides of the channel.



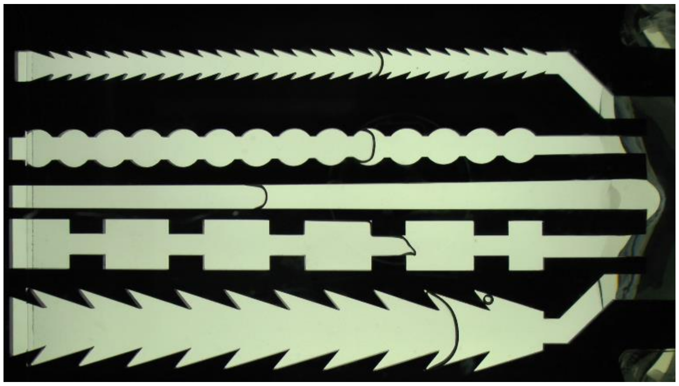
Like the preceding experiment, this 2018 experiment from Green Valley High School (Henderson, NV) examines the effect of cavities on one, both, or no sides of the channel. But in this case, the cavities are triangular rather than elliptical.



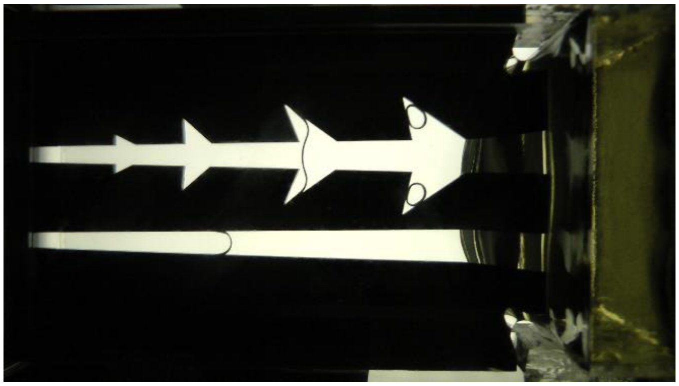
This 2013 experiment from the Niles Middle School (Niles, OH) is similar to the previous experiment, but instead investigates the effect of the cavity shape, specifically elliptical vs. triangular, where the cavities are on one side of the channel.



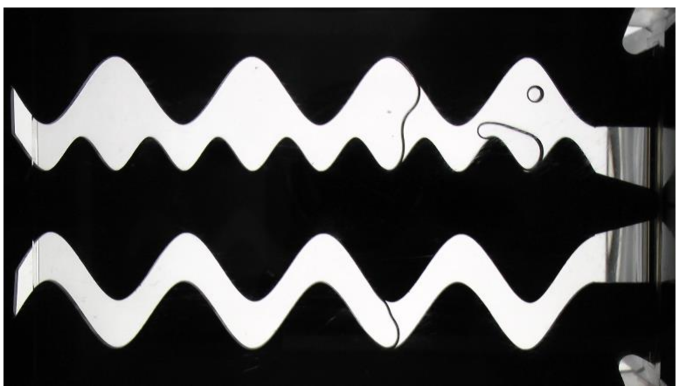
This 2017 experiment from The Overlake School (Redmond, WA) examined the effect of triangular cavities – pointed upwards, downwards, and orthogonally – on the upward motion of the silicone oil.



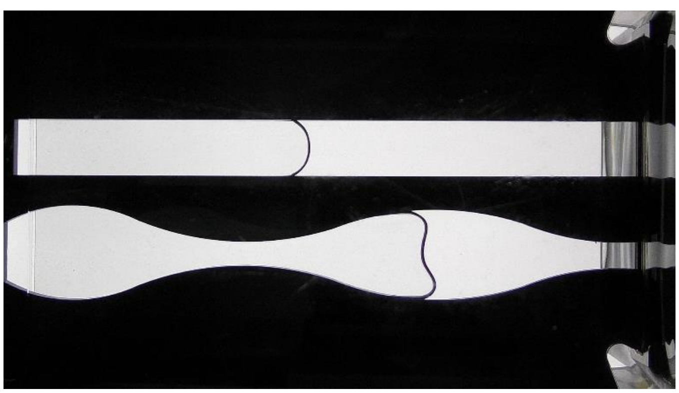
This 2014 test cell from Villa Angela - St. Joseph High School (Cleveland, OH) effectively includes two experiments. The three central channels are used to evaluate the effect of the circular and rectangular cavities on the capillary motion. The two outermost channels were used to assess the influence of the size of triangular cavities on the capillary motion, after a bend in the path.



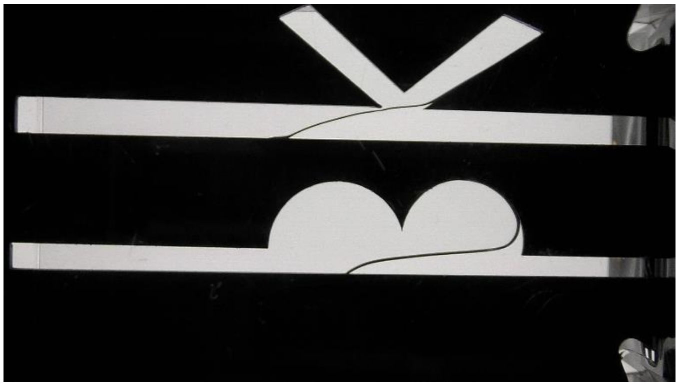
This 2013 experiment from the Niles Middle School (Niles, OH) examines the effect of triangular cavities on capillary motion in a narrowing channel. In contrast, most of the CELERE experiments investigating cavity effects have thus far used channels of a constant width (of course neglecting the cavities themselves).



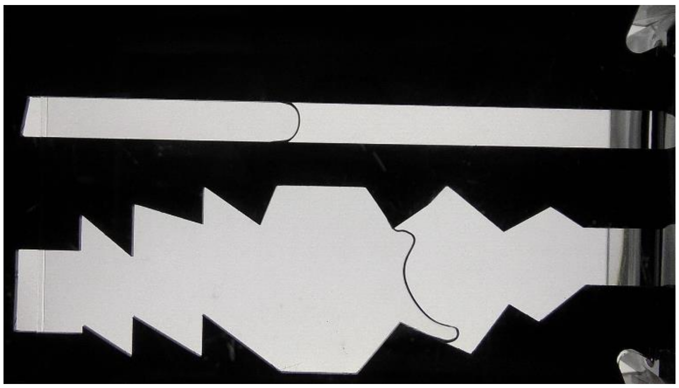
This 2016 experiment from the Council Rock High School South (Holland, PA) examines the effect of cavities on the capillary action within zigzagging channels.



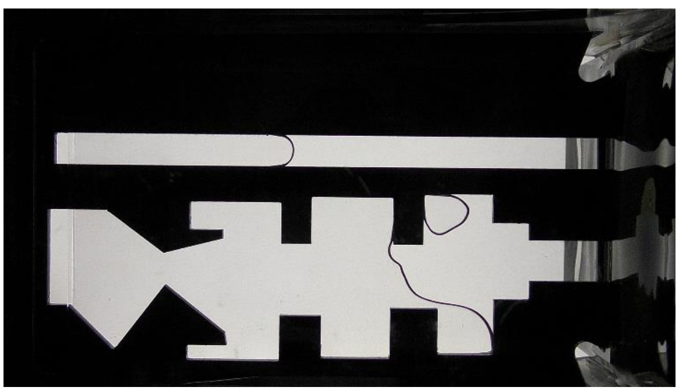
This 2016 experiment from Michigan City High School (Michigan City, IN) investigates the effects of smoothly expanding and contracting cavities on the capillary action.



This 2017 experiment from Bishop Kearney High School (Brooklyn, NY) examined the effect of letter-shaped cavities on the rise of the silicone oil. Unfortunately, the considerable difference between the letter shapes complicates the interpretation of the results.



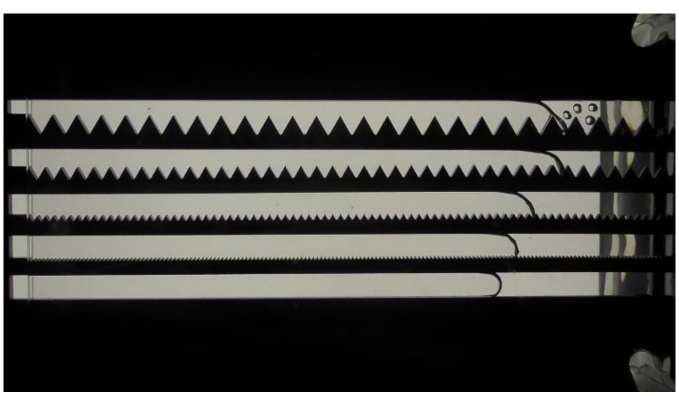
This 2017 experiment from Bishop Kearney High School (Brooklyn, NY) examined the effect of irregular (mostly) triangular cavities on the rise of the silicone oil. Interpretation would have been facilitated with the use of regular cavities.



Like the preceding experiment, this 2017 experiment from Bishop Kearney High School (Brooklyn, NY) examined the effect of irregular cavities on the rise of the silicone oil. Interpretation would have been facilitated with the use of regular cavities.

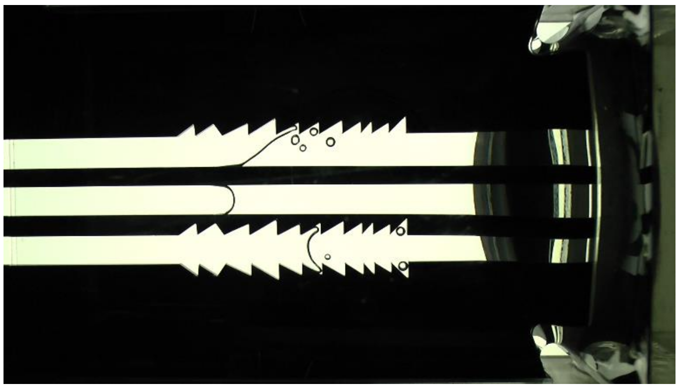
7. Effects of Channel Roughness

Note that up is to the left in these images, and down is to the right (i.e., where the cameras was on its side).

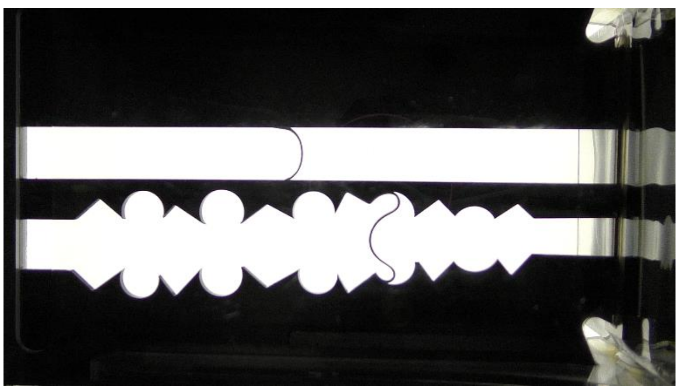


This 2018 experiment from The Overlake School (Redmond, WA) examined the effect of uniform triangular roughness on one channel wall on the motion of the fluid. The use of five channels allowed a wide degree of variation in the roughness (including none).

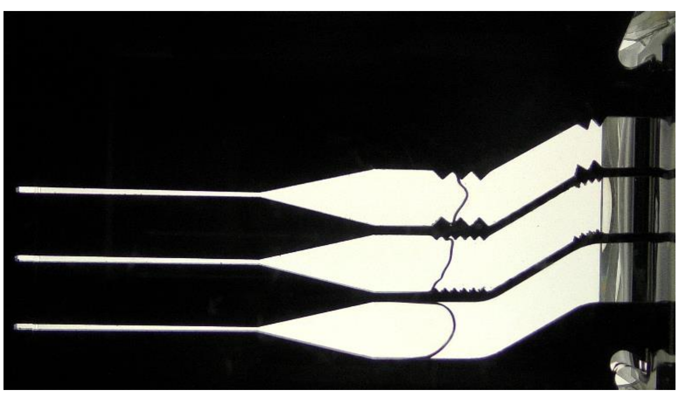
This 2014 experiment from St. Ursula Academy (Toldeo, OH) explored the effect of channel roughness on the capillary motion.



This 2014 experiment from St. Ursula Academy (Toldeo, OH) is similar to the previous one and again explored the effect of channel roughness on the capillary motion, but in this case the roughness is on one, both, or neither side of the channel.



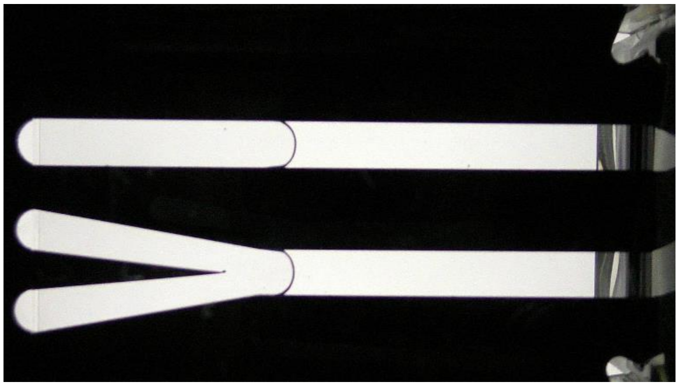
This 2016 experiment from Bishop Kearney High School (Brooklyn, NY) investigates the effect of a sequence of small varying cavities on the motion of the oil.



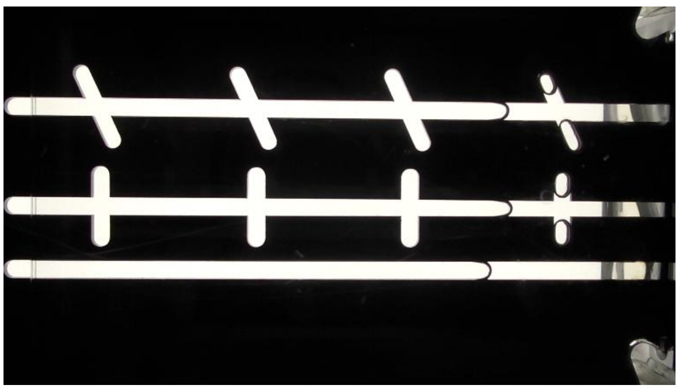
This 2017 experiment from Council Rock High School South (Holland, PA) examined the effect of channel roughness on the rise of the fluid through bending channels.

8. Effects of Branching

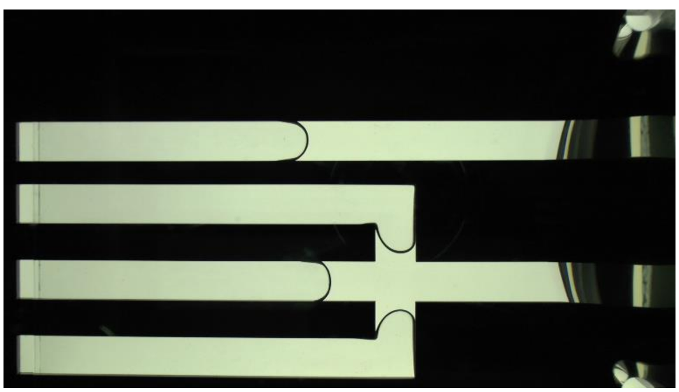
Note that up is to the left in these images, and down is to the right (i.e., where the cameras was on its side).



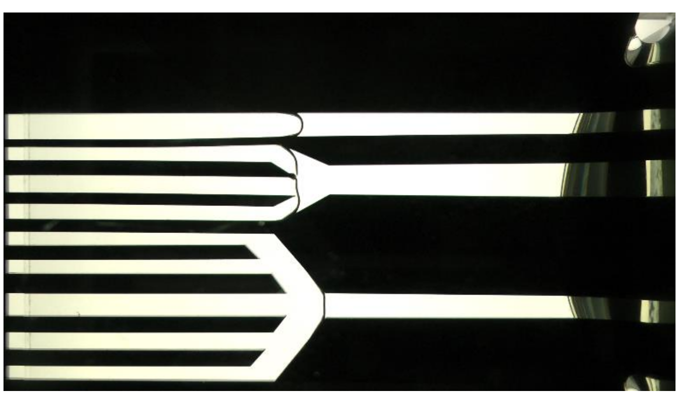
This 2017 experiment from Bard High School Early College Manhattan (New York City, New York) investigates the effect of a Y-shaped branch on the fluid's motion.



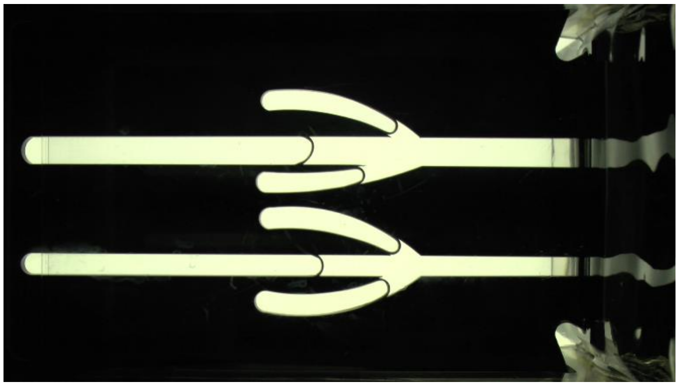
This 2018 experiment from Stuyvesant High School (New York, NY) examined the effect of recurring branches at different angles on the oil's motion.



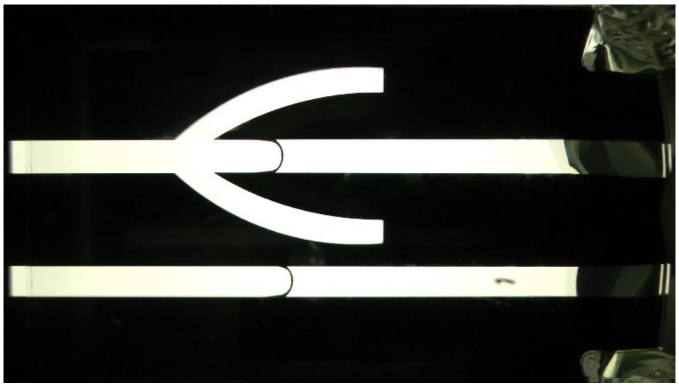
This 2014 experiment from St. Edward High School (Lakewood, OH) explores the effect of a branching channel, with an orthogonal four-way intersection, on the capillary motion.



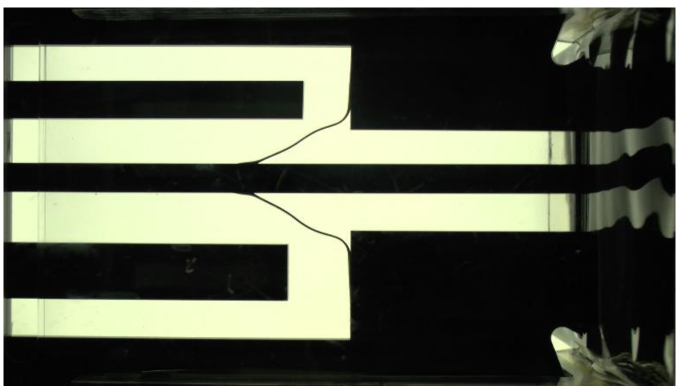
This 2014 experiment from St. Edward High School (Lakewood, OH) is similar to the previous one, but explores the branching effect with branches which are angled upward.



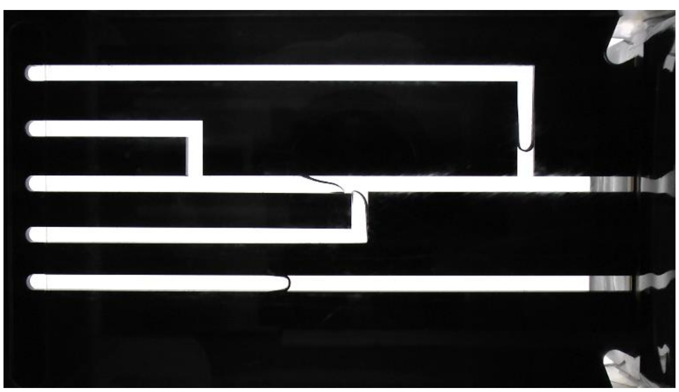
This 2015 experiment from California High School (Ramon, CA) examined the effect of the branching angle, where the branches were dead-end paths.



This 2014 experiment from St. Edward High School (Lakewood, OH) explores the effect of branching into dead-end paths (oriented in the reverse direction) on the capillary motion.



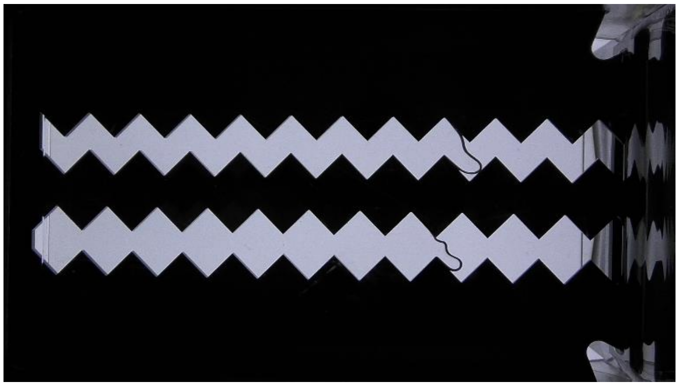
This 2015 experiment from St. Ursula Academy (Toldeo, OH) explored the effect of the channel width on branching flow.



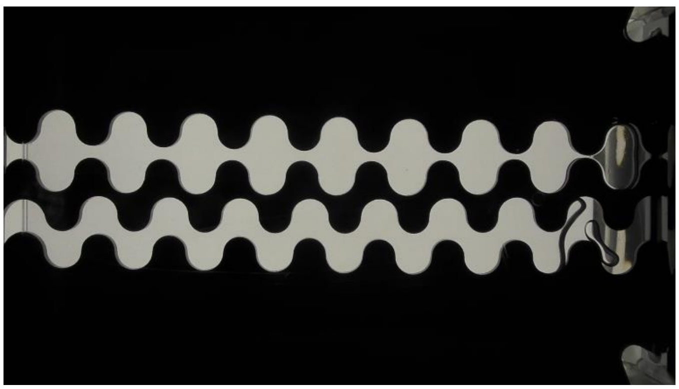
This 2016 experiment from the Jonas Clarke Middle School (Lexington, MA) investigated the effect of repeated channel branching on the capillary flow.

9. Miscellaneous

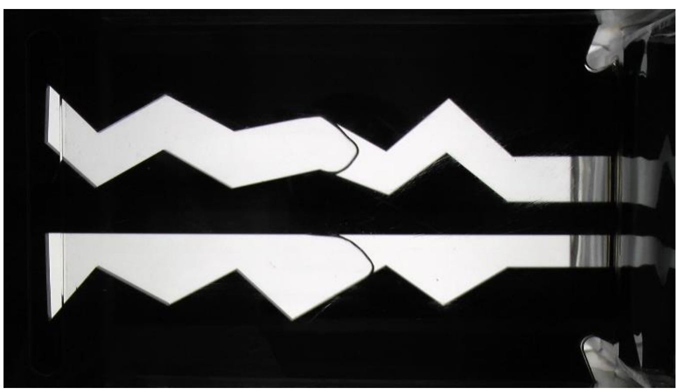
These experiments don't fit well in the other categories but are appropriate experiments.



This 2016 experiment from the Thomas Jefferson H.S. for Science & Technology (Fairfax, VA) has channels which match on one side, but differ on the other size. This design resulted in the comparison of a zigzagging channel with a channel with repeating cavities.



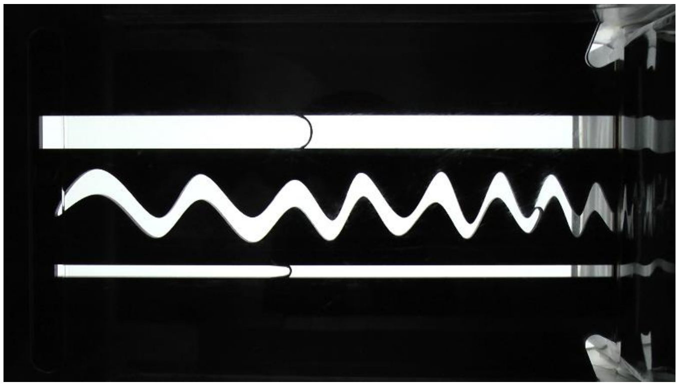
This 2018 experiment from Centro Residencial de Oportunidades Educativas de Mayagüez (CROEM, Mayagüez, Puerto Rico) is similar to the preceding experiment, but it has smoothly undulating channel walls.



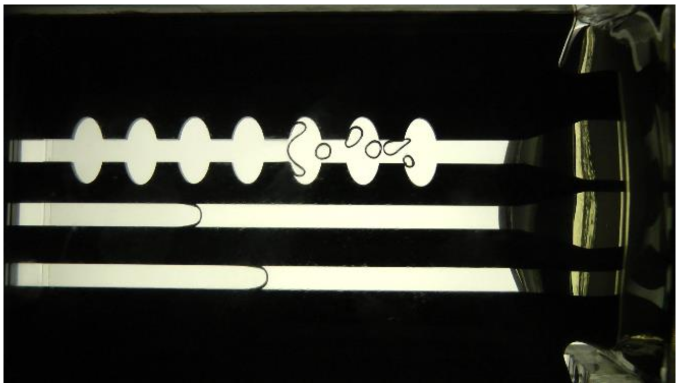
Like the preceding entry, this 2016 experiment from Wickliffe High School (Wickliffe, OH) has channels walls that are nominally identical on one side but differ on the other side.

10. Combined Effects

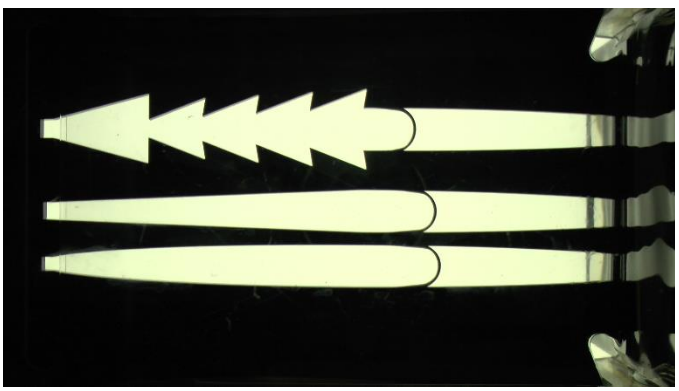
Submissions with combined effects are generally discouraged unless each effect can be assessed independently through the careful use of three or more channels! Most of the experiments in this section do not follow the design rule that "the channels should ideally differ in a single way." *Note that up is to the left in these images, and down is to the right (i.e., where the cameras was on its side).*



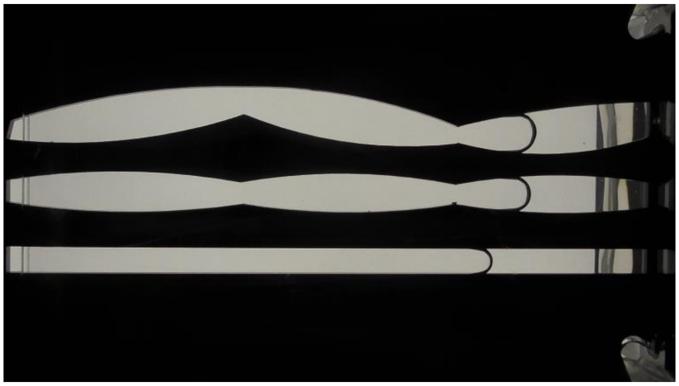
This 2016 experiment from Wickliffe High School (Wickliffe, OH) is an appropriate example of a test cell investigating multiple effects. Comparison of left and right channels allows for assessment of the channel width effect. Meanwhile, comparison of the left and center channels allows one to investigate the effect of the channel path. If two effects are being studied than a test cell should have at least three channels, as was the case in this experiment.



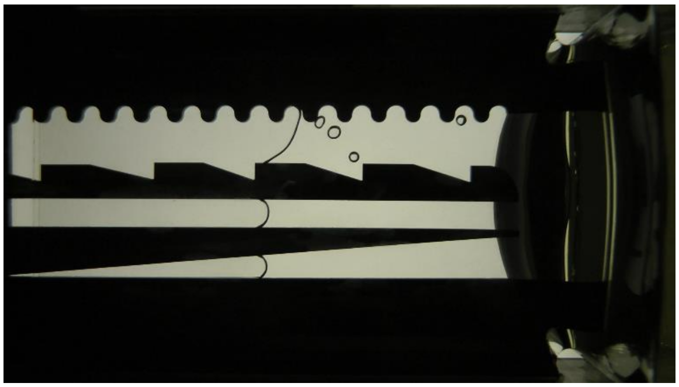
Although it is not clear from the image, this 2013 experiment from the Niles Middle School (Niles, OH) includes two different effects. The left channel (i.e., bottom in the image) is vertical with straight walls, the center channel includes a uniformly narrowing channel entry, and the right channel further adds the elliptical cavities. Comparison of the first two channels allows assessment of the entrance section, while comparison of the second and third channels allows study of the cavities. This is an appropriate use of combined effects, where two experiments are conducted with one test cell.



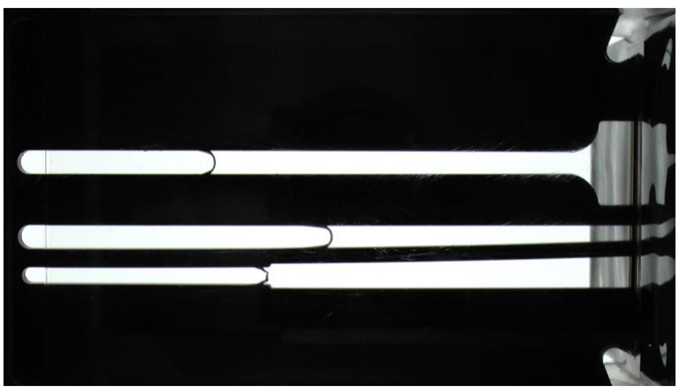
This 2015 experiment from Park High School (Livingston, MT) includes multiple experiments, where the effect of the channel shape can be compared in the leftmost channels (i.e., which are on the bottom in this image). While not immediately obvious, the left channel has elliptical walls, while the top of the center channel uniformly narrows with height. Meanwhile, the right channel (i.e., on the image's top) can be compared with the leftmost channel to assess the effect of the triangular cavities on the oil's motion. Again, this is an appropriate use of combined effects.



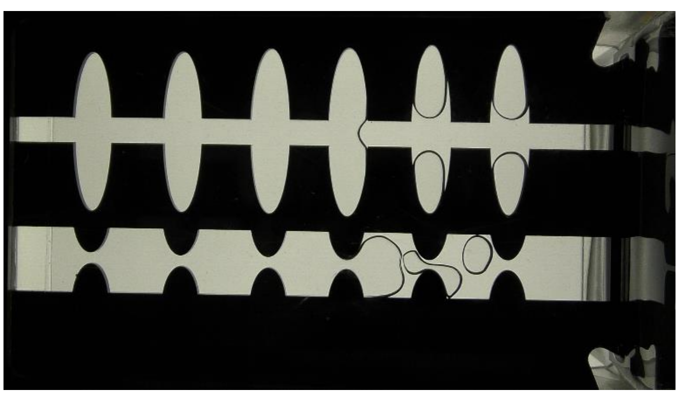
This 2018 experiment from Da Vinci Communications High School (El Segundo, CA) allows investigation of slight wall curvature by comparison of the two leftmost channels and the channel path by comparison of the two rightmost channels. This is an appropriate use of combined effects.



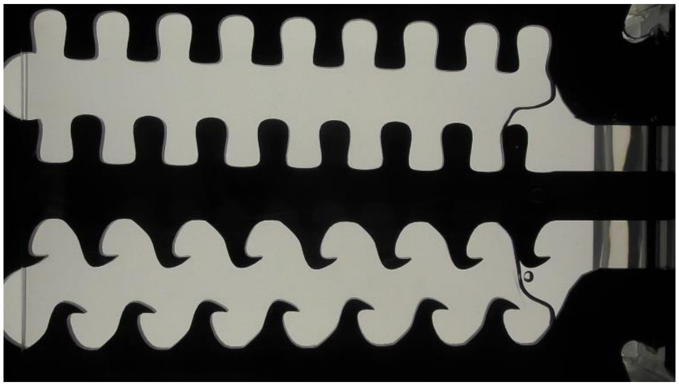
This 2013 test cell from St. John's Jesuit High School and Academy (Toledo, OH) includes multiple experiments, where the effect of channel narrowing can be assessed from the two leftmost channels (i.e., which are on the bottom in this image), whereas the two rightmost channels allow an assessment of cavity effects, where cavities of different shapes are included. This is also an appropriate use of combined effects.



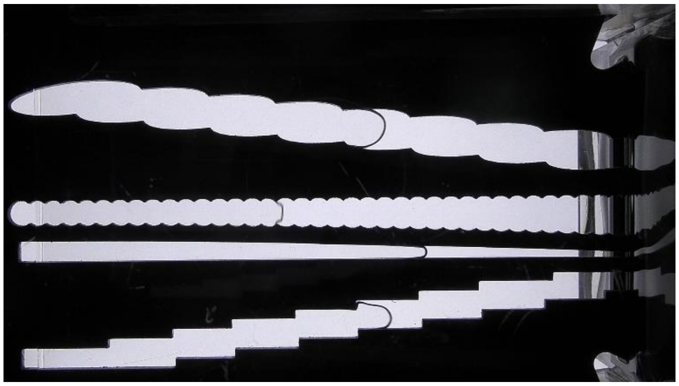
This 2016 experiment from the Jonas Clarke Middle School (Lexington, MA) examined the effect of uniform contractions on the capillary flow, but those contractions (in the left and right channels differ) in both size and location, complicating the interpretation of the results. <u>However</u>, this test cell would have been an appropriate use of combined effects. That ceased to be the case when the ‘island’ formed from merging channels was eliminated, leaving a wide inlet section in the right (top) channel, whereas it had been two channels consistent with the other two channels.



This 2016 experiment from the Rachel Carson Middle School (Herndon, VA) investigated the effect of repeating ellipsoidal cavities and protrusions, but the channel width (where straight) also varies where having it constant would have simplified the interpretation of results.



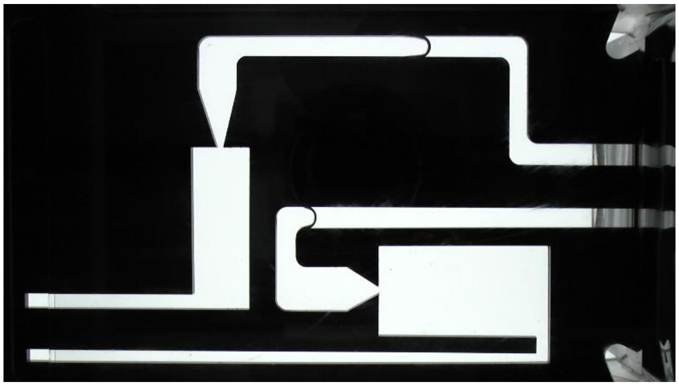
This 2018 experiment from Bartram Trail High School (St. Johns, FL) examines the effects of opposed and alternating cavities, but the analysis would have be simplified if they had the same or similar shape. Alternately, if the goal was to study the shape of the cavity then it would have aided interpretation for the cavities' arrangement to be the same or similar.



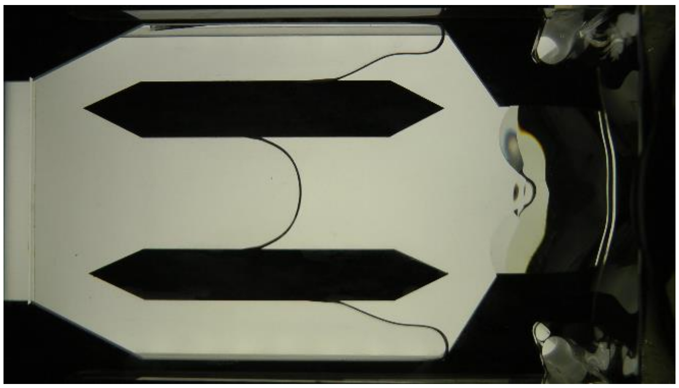
This 2017 test cell from Canyon Crest Academy (San Diego, CA) effectively includes two experiments through its use of multiple channels. The outer channels allow comparison of rounded vs. sharp cornered cavities. Meanwhile, the inner channels differ in multiple ways, complicating interpretation.

This 2017 experiment from the Carmel Valley Middle School (San Diego, CA) studied the effect of zigzagging paths on the rise of the oil, where the channels differed in thickness, bend angle, and entry into the first bend, which complicates the comparison.

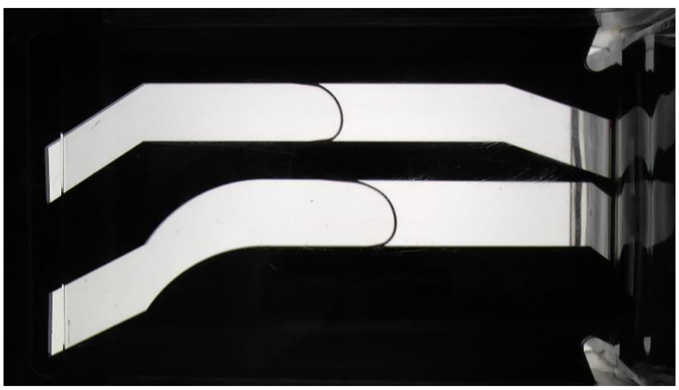
This 2018 experiment from the Canyon Crest Academy (San Diego, CA) is a minor variant of the preceding experiment, where the channels differed in thickness, bend angle, and entry into the first bend. However, the channel width is nominally consistent in each channels in this version, which is a simplification. Nonetheless, the combined differences makes it difficult to interpret the results.



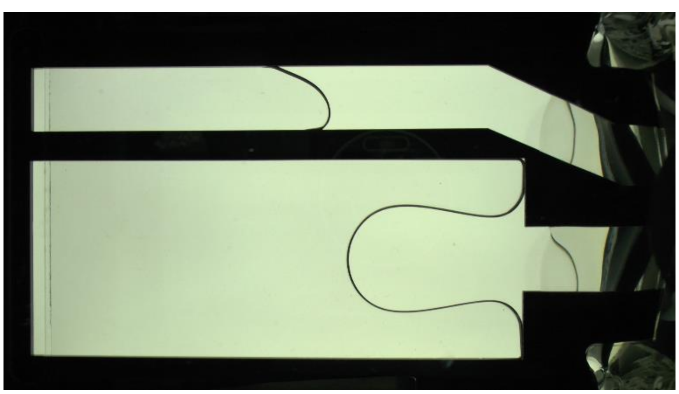
This 2016 experiment from the Illinois Mathematics and Science Academy (Aurora, IL) intended to investigate the motion of the oil in sudden expansions, but the channels were too long for the oil to reach the contractions during the drop. But it must also be recognized that the paths of the two channels varied in direction and length, which would have complicated interpretation of the results.



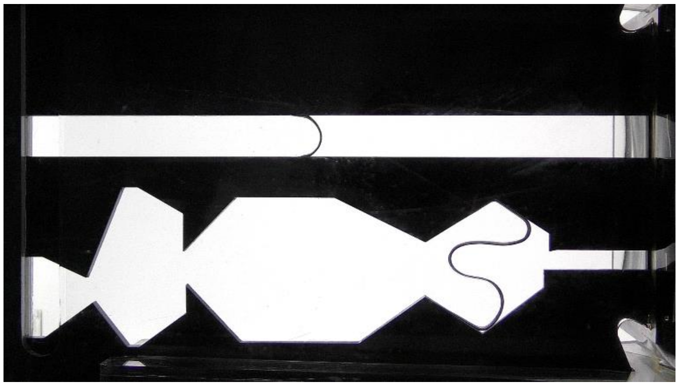
This 2013 test cell from the St. Ursula Academy (Toldeo, OH) includes the effects of both different channel widths and different channel paths, i.e., vertical vs. bent, on the capillary action.



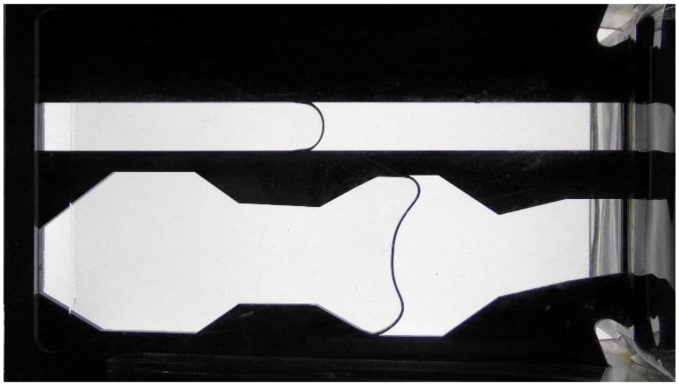
This 2016 experiment from Wickliffe High School (Wickliffe, OH) has channels that differ in path and shape (sharp vs. rounded corner) – near the bottom and top of the test cell, respectively.



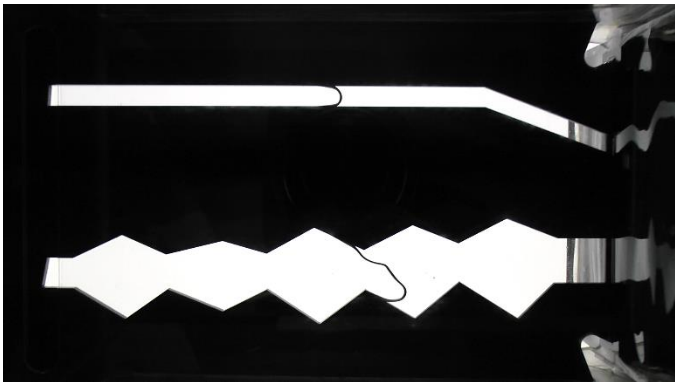
This 2014 test cell from the St. Ursula Academy (Toldeo, OH) includes the effects of both abrupt expansion and different channel paths, i.e., vertical vs. bent, on the capillary action.



This 2016 experiment from Bishop Kearney High School (Brooklyn, NY) includes the effects of both the channel width (in the lower portion of the channels) and the abrupt expansion on the capillary motion.

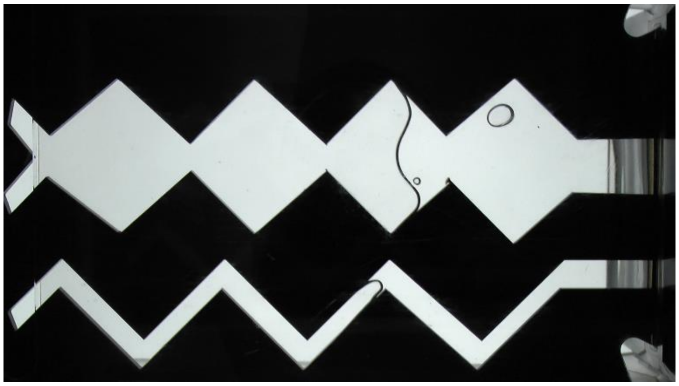


This 2016 experiment from Bishop Kearney High School (Brooklyn, NY) includes the effects of the channel width, channel path (i.e., vertical vs. bent), and the cavities on the capillary flow.

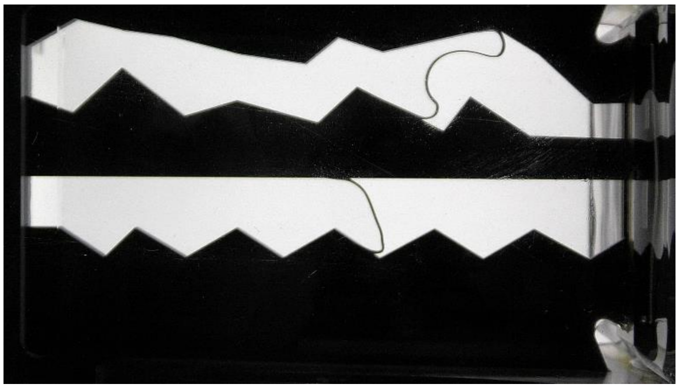


Like the preceding experiment, this 2016 entry from Wickliffe High School (Wickliffe, OH) has channels that differ in width, path, and repeating cavities (or not).

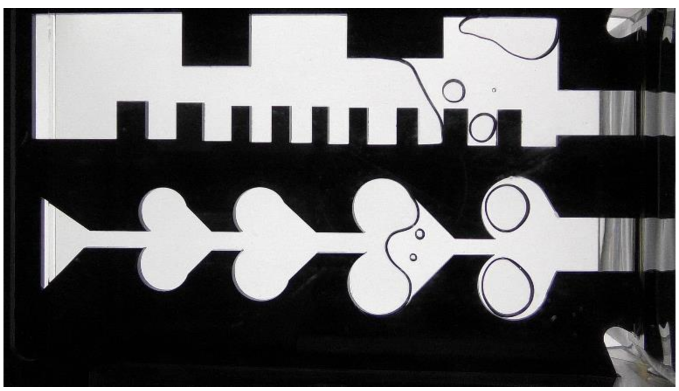
This 2016 experiment from the Alief Early College High School (Houston, TX) examined the effects of both the channel width and the path of the zigzagging channels on the capillary motion of the oil.



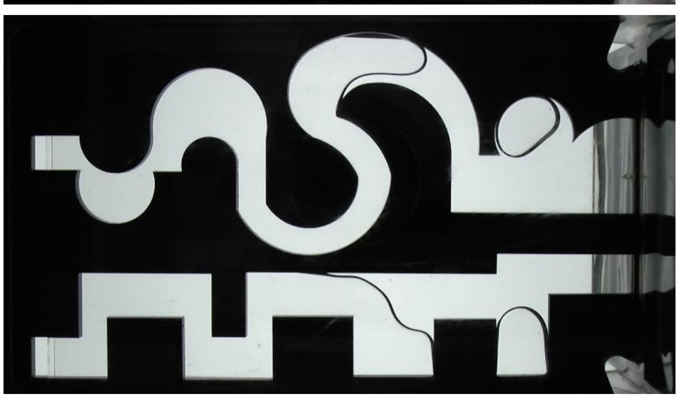
This 2016 experiment from the Alief Early College High School (Houston, TX) examined the effects of the channel width (at the base of the test cell), channel path, and repeating cavities on the oil's motion.



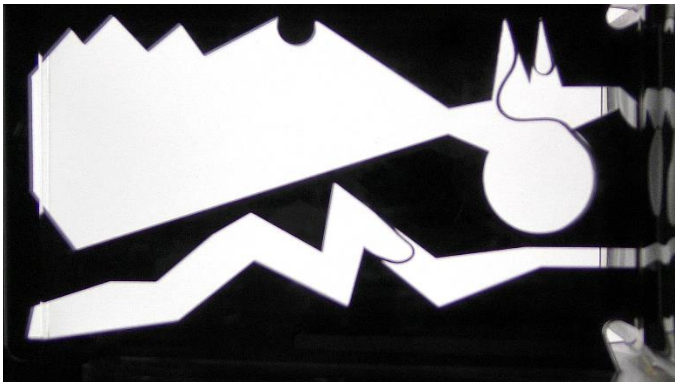
This 2016 experiment from Bishop Kearney High School (Brooklyn, NY) includes the effects of different variations in the two edges of the channels. If the both channels were the same on one side (left or right), it would be much easier to learn from the experiment.



This 2016 experiment from the Alief Early College High School (Houston, TX) includes channels that differ in multiple ways, where the cavities in the two channels differ greatly and thereby complicate any analysis.



Like the previous experiment, this 2016 entry from Wickliffe High School (Wickliffe, OH) has channels that are different in many ways making it difficult to assess what caused the differences in the oil's behavior.



In contrast to the rule that “the channels should ideally differ in a single way,” the channels in this 2016 experiment from Wickliffe High School (Wickliffe, OH) again differ greatly from each other.

This 2017 experiment from Bishop Kearney High School (Brooklyn, NY) includes channels that differ in angle, width, cavity shape and size, and the number of sides on which the cavities are present. The multiple differences between the two channels significantly complicate the interpretation of the results.