Liquid Lens
Get Wet Project
Flow Visualization Fall 2007
Tracy Eliasson

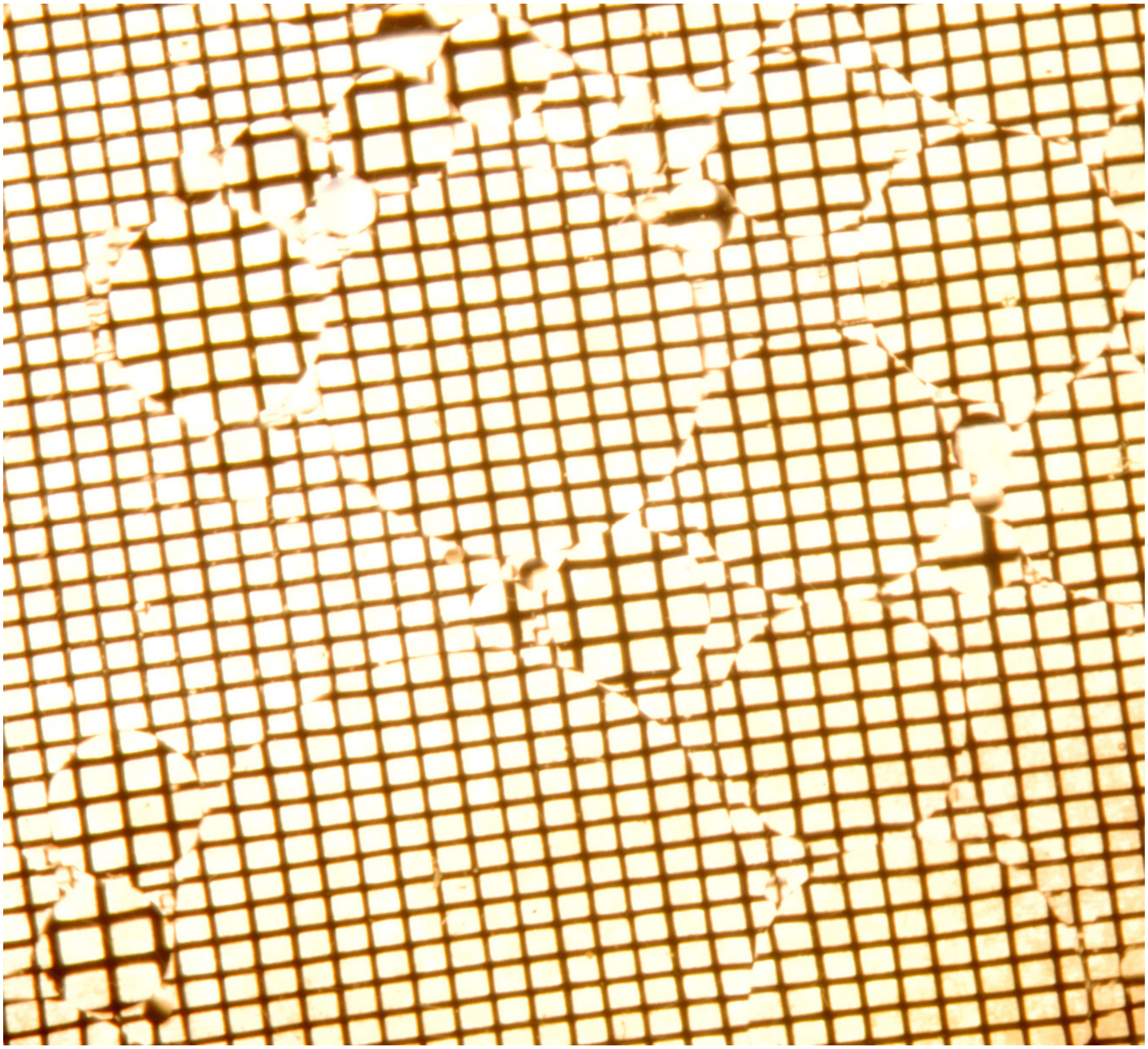
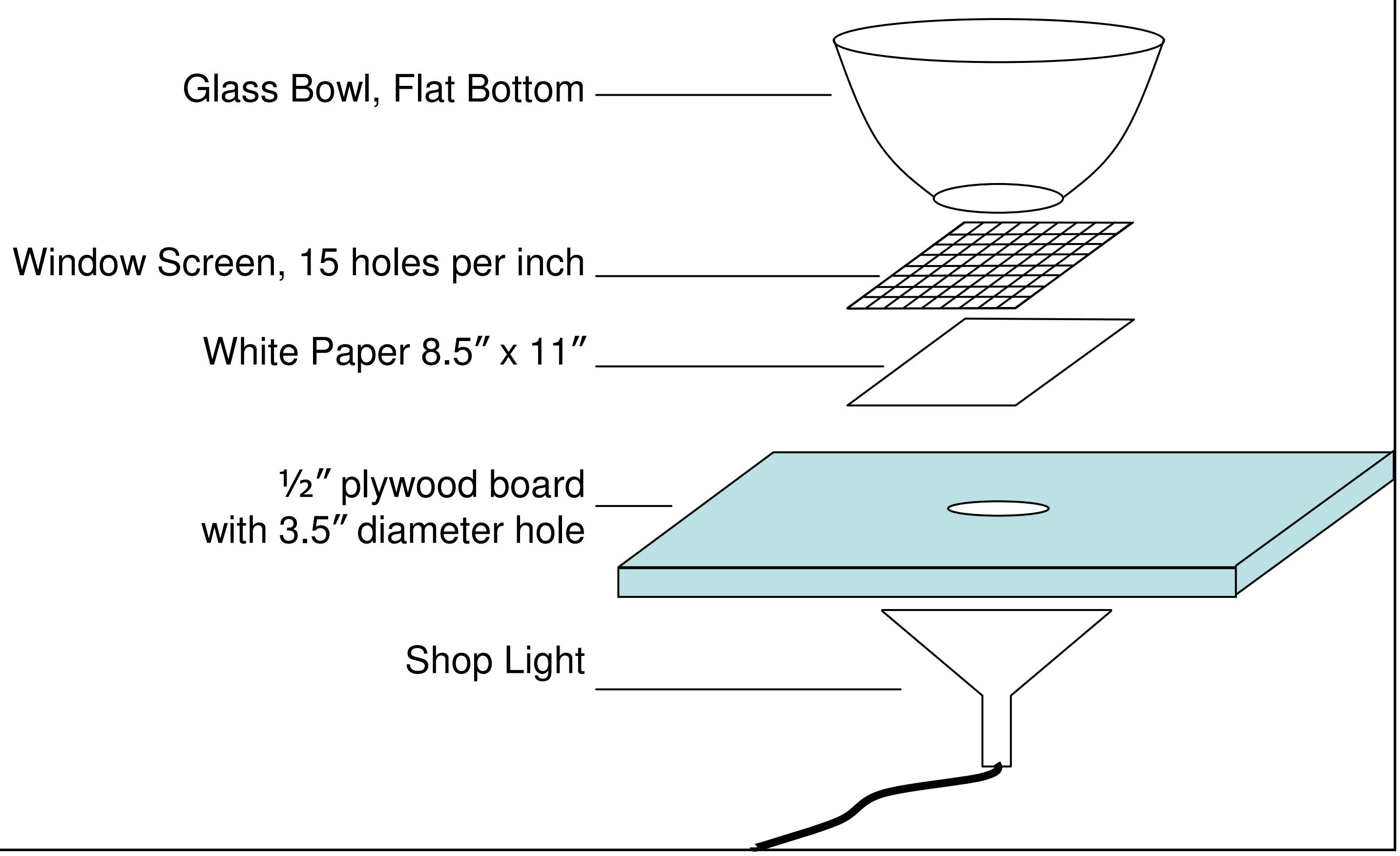


Figure 1: Image of Liquid Lens

The photograph, shown in Figure 1, is the result of the "Get Wet" project for the 2007 Flow Visualization course at the University of Colorado. The intent is to record the magnifying lens properties of several olive oil pools suspended on the surface of water. Oil droplets of various diameters assume various lens shapes and thus have varying magnification properties. The resulting image is both visually stimulating and scientifically interesting.

Figure 2 shows a sketch of the flow apparatus. A ½" plywood scrap board was used as the base for the apparatus. A 3.5" diameter hole was cut into the board so that the scene could be backlit. A sheet of white office paper was laid over the hole in the board and then covered with a piece of

Figure 2: Apparatus

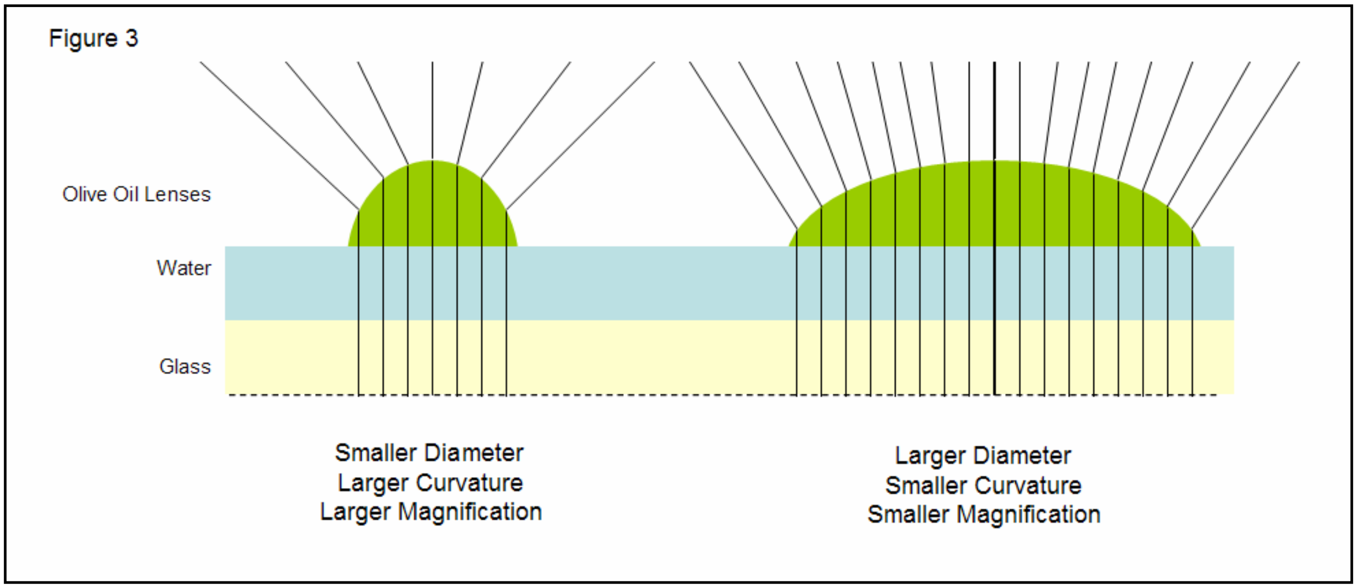


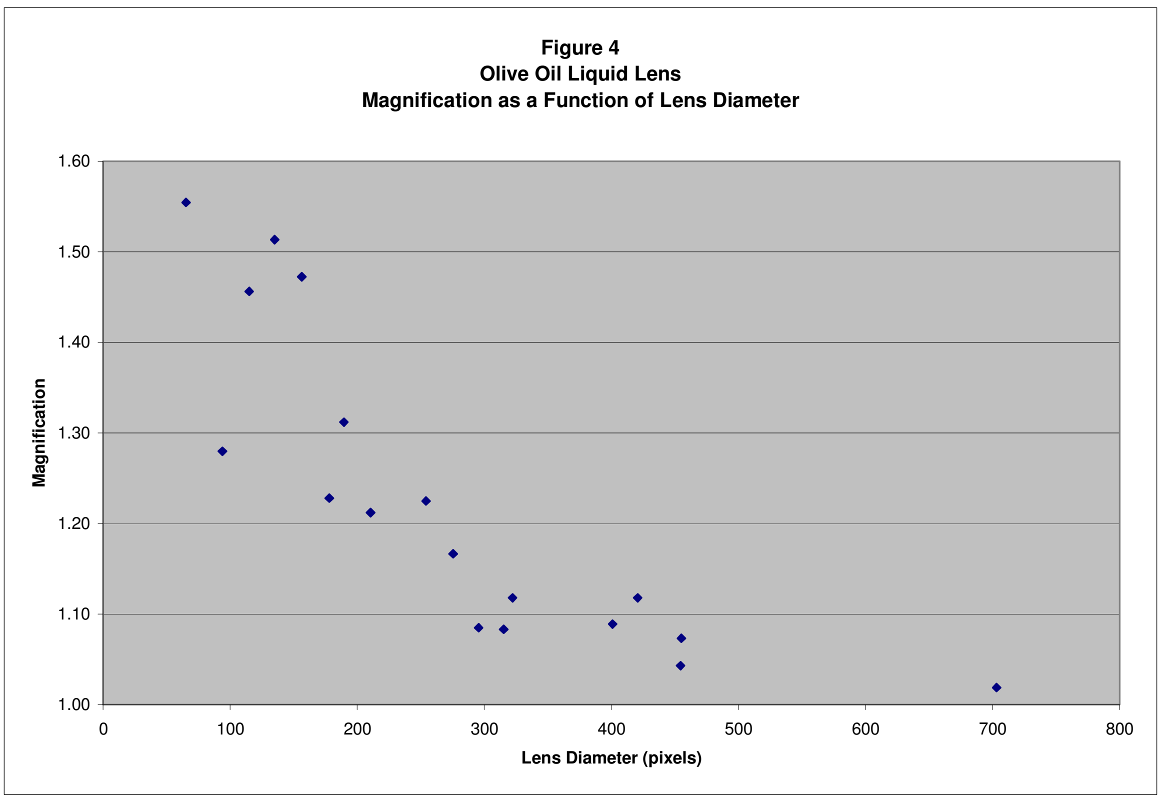
window screen. This screen serves as a grid to be imaged, and allows visualization and measurement of the magnification that is present. The screen has 15 squares per linear inch. On top of the screen a flat bottom glass bowl was set. Approximately 1″ of water was added to the bowl along with about 1 teaspoon of olive oil. The liquid in this image is stationary; therefore the Reynolds and Grashof numbers are not applicable. The material property that is relevant is the index of refraction. Table 1 provides this value for glass, water, olive oil, and air. Figure 3 shows a model of the light bending of olive oil lenses with different diameters. Figure 4 relates the magnification of each lens to the diameter of that lens. Raw data for these measurements are included in the form of Appendices. The data indicate that the magnification approaches one as the lens diameter grows. This is because the lens curvature is less as the lens diameter increases, gravitational forces outperform surface tension. The field of view shown in the image is roughly 2″ by 2″. The index of refraction of olive oil (1.468) is higher than that of air (1.00). This explains why light is bent away from the normal as it exits the lens.

Table 1

Material	Index of Refraction
Glass	1.52[1]
Water	1.33[2]
Olive Oil	1.468[3]
Air	1.00[4]

[1] Serway, Raymond A (1992) Physics for Scientists and Engineers.Chicago: Saunders College Publishing.
[2] Serway, Raymond A (1992) Physics for Scientists and Engineers.Chicago: Saunders College Publishing.
[3] P. Miller, K. Danielson, G. Moody, A. Slifka, E. Drexler, and J. Hertzberg. (2006). Matching Index of Refraction Using a Diethyl Phthalate/Ethanol Solution for In-Vitro Cardiovascular Models. Experiments in Fluids, 41, 375-381.





In order to observe the light bending qualities of the liquid lenses a window screen was utilized. Without this window screen to serve as a grid it is difficult to see the extent of light bending, or the variation in magnification from oil drop to oil drop. Front light (from sunlight, light fixtures, and the camera flash) caused both distracting glare and shadows from the lenses upon the white paper. The scene was backlit in order to provide enough light and eliminate distractions.

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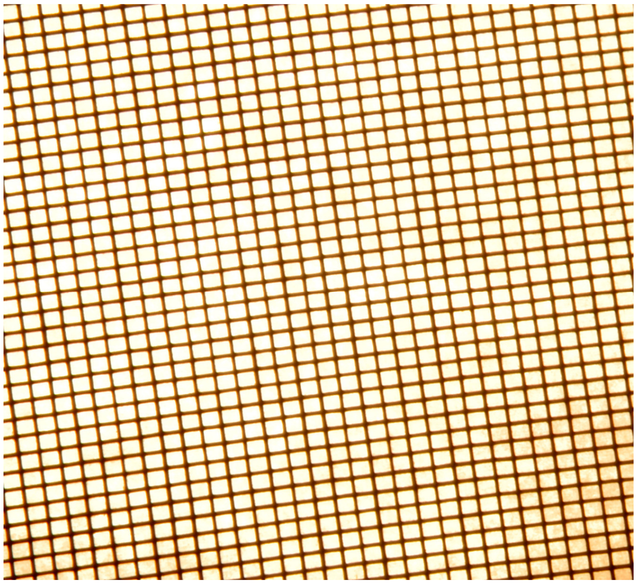
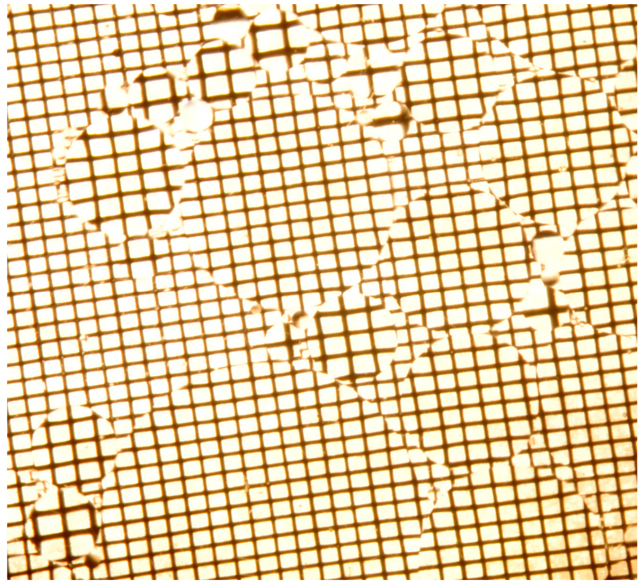
[4] Serway, Raymond A (1992) Physics for Scientists and Engineers.Chicago: Saunders College Publishing.

The photograph was captured with a Nikon D80 digital camera mounted on a tripod above the bowl of water and oil. The field of view is approximately 2" by 2". The distance between the object and the lens was approximately 30". The lens used has variable focal length of 28-135mm F/3.8-5.6D. A focal length of 122mm was used for this photograph. The exposure was taken for 3.6 seconds with an aperture of F/36. This aperture was chosen in order to have the greatest focal length possible, many focal distances (from the screen height, to the top of the oil surfaces) were considered important for the photograph. The ISO setting was 100. Minimal image processing was done with Photoshop Elements. The image was cropped in order to choose a field of view that provides both interesting image composition and good examples of various magnifications from various droplets. The image levels were also adjusted slightly.

This image reveals the lens characteristics of oil floating on water. It reveals that the magnification power of the lens is a function of the oil diameter. The lens physics are easily captured with the apparatus. It is interesting to examine the imaging chain characteristics of liquid while at the same time utilizing an imaging chain to capture the data. The apparatus is simple, inexpensive, and safe. This visualization technique could be used to teach children about lenses, magnification, and fluids. It would be interesting to use this visualization technique with moving fluids. The patterns and light bending seen during and just after image mixing are quite interesting, but did not lend themselves to the analytical lens analysis. Further experiments with Oils of various colors should be pursued in order to accentuate the lens locations, no oils with adequate color contrast were located as part of this work.

Appendix 1:
The images shown here are 1) an image of the apparatus just before the oil was added, and 2) the liquid lens photo after the olive oil was added. The image on the left was used as a baseline in order to calculate the magnification of each liquid lens.


Scene Before Oil Added


Scene with Oil Lenses Present

Appendix 2:
Baseline measurements and calculations based on the "Scene Before Oil Added" photograph. Both aspect ratio and baseline resolution are determined.

Trial	Width	Height	# Squares Across	# Squares High	Pixels / Square Across	Pixels / Square High	Aspect Ratio (height / width)
1	437	356	10	10	43.7	35.6	1.2
2	437	365	10	10	43.7	36.5	1.2
3	425	365	10	10	42.5	36.5	1.2
4	436	374	10	10	43.6	37.4	1.2
5	438	363	10	10	43.8	36.3	1.2
				average:	43.5	36.5	1.2
				stdev:	0.5	0.6	0.0

Appendix 3:
Measurements and calculations for each "lens" (olive oil present). Note, although the aspect ratio is not 1 the magnification in the x direction matches that in the y direction. This is as expected.

Trial	Width	Height	# Squares Across	# Squares High	Pixels per Square Across	Pixels per Square High	Magnification X Direction	Magnification Y Direction	Average Magnification
A	162	132	3	3	54.0	44.0	1.24	1.21	1.22
B	66	58	1	1	66.0	58.0	1.52	1.59	1.55
C	64	105	1	2	64.0	52.5	1.47	1.44	1.46
D	66	55	1	1	66.0	55.0	1.52	1.51	1.51
E	93	85	2	2	46.5	42.5	1.07	1.17	1.12
F	161	130	3	3	53.7	43.3	1.23	1.19	1.21
G	230	119	5	3	46.0	39.7	1.06	1.09	1.07
H	196	202	4	5	49.0	40.4	1.13	1.11	1.12
I	183	203	4	5	45.8	40.6	1.05	1.11	1.08
J	273	303	6	8	45.5	37.9	1.05	1.04	1.04
K	116	141	2	3	58.0	47.0	1.33	1.29	1.31
L	241	116	5	3	48.2	38.7	1.11	1.06	1.08
M	107	134	2	3	53.5	44.7	1.23	1.23	1.23
N	63	109	1	2	63.0	54.5	1.45	1.49	1.47
O	358	294	8	8	44.8	36.8	1.03	1.01	1.02
P	236	199	5	5	47.2	39.8	1.09	1.09	1.09
Q	54	48	1	1	54.0	48.0	1.24	1.32	1.28
R	106	203	2	5	53.0	40.6	1.22	1.11	1.17

Appendix 4:
Lens Diameter Measurements and Calculations

Lens	Width 1	Height 1	Width 2	Height 2	Width 3	Height 3	Diameter
A	252	256	255	254	250	257	254
B	68	66	63	67	62	66	65
C	114	116	120	115	111	114	115
D	143	129	136	139	134	130	135
E	421	421	412	433	417	420	421
F	223	206	211	208	206	210	211
G	285	499	477	495	473	501	455
H	316	324	323	320	319	331	322
I	318	314	316	313	309	322	315
J	448	461	458	449	450	461	455
K	197	164	195	191	197	193	190
L	294	298	291	304	297	289	296
M	182	180	185	174	171	176	178
N	155	158	155	156	161	153	156
O	689	729	678	725	674	724	703
P	404	407	401	395	395	403	401
Q	96	97	92	93	92	93	94
R	287	267	276	273	271	279	276