As object moves closer, lens moves away from sensor plane. Mechanical limit defines near focus distance. Extension tubes (for DSLR) allow lens to move further out and focus closer. $75 set of 3

'Close up' lenses allow close focus by changing system \( f \). Long \( f \) lens, threads on to the outer end of main lens (threads standard, but need to match diameters).

Lower quality, though. Each additional lens element can lose 10% of light, introduce aberrations.

PHD cameras often lack threads. Just hold it out in front, or mount to cardboard tube. Check focus often.

Inexpensive, $6 for set of 4

Spec'd in 'diopters' = \( 1/f \) in meters. Typically +1, +2, +4

\[
\frac{1}{f_{\text{TOTAL}}} = \frac{1}{f_1} + \frac{1}{f_2}
\]

PHD cameras often have 'macro mode' = Flower Button. Does yours?

For DLSRs, prime and zoom 'macro' lenses are available. Expect high price, hope for quality.
OUT OF FOCUS

Image plane, sensor plane, FOCUS plane

Not a point; looks like a circle; Circle of Confusion

Depth of Field

Image plane, sensor plane, FOCUS plane

OK range, circles are small enough to be ignored

Depth Of Field = DOF

LensBaby

Improve DOF by reducing diameter: smaller hole, better depth of field

More DOF behind point of focus than in front
Image plane, sensor plane, FOCUS plane

OK range, circles are small enough to be ignored

Depth Of Field = DOF

Aperture (iris) mechanism made from overlapping pivoting leaves.

Aperture has impact on exposure too, how much light total hits the sensor.
Units: 1 stop = 1 EV Exposure Value = factor of 2 in area, light.
Camera adjustments in 1/3 stops

Stop used to be a metal plate with hole punched in it.

http://media.wiley.com/assets/1007/41/0-764-5-9802-3_0213.jpg
http://synapticlight.com/iris-and-aperture/

2.8, 3.5, 4, 5.6, 8, 11, 16, 22, 32, 45, 64

Ansel Adams founded f/64 club. Tiniest hole, maximum DOF. Modern lenses often best sharpness at f/5.6 or design point.

4. EXPOSURE
For a given intensity, \( \approx \) area \( \times \) time shutter is open

\[
\frac{5.6}{f/4, 1/100 \text{ sec}}
\]

Equivalent exposures:
\[
\frac{f/8, 1/50 \text{ sec}}{f/11, 1/25 \text{ sec}}
\]

Image 'density', average pixel values also depends on sensor gain, sensitivity: ISO (ASA historically)
1 EV, stop = factor of 2 in ISO
\[
\frac{5.6}{f/8, 1/100 \text{ sec}, \text{ ISO 200}}
\]

Same image density \( f/4, 1/100 \text{ sec}, \text{ ISO 400} \)
How to choose?

Minute paper: list pros and cons of

1) small aperture vs large aperture
2) short shutter (high shutter speed) vs long (slow)
3) high ISO vs low

4) Aperture: large f/ = better DOF, but less light, maybe less sharpness overall
5) Short shutter = freeze the flow, minimize motion blur, but less light
6) High ISO adds noise

Usually, set ISO for overall conditions, then choose
Av = aperture priority, let AE (auto exposure) choose shutter
or
Tv = shutter priority, AE chooses aperture