Lecture 37: Lenses and mirrors

- Spherical lenses: converging, diverging
- Plane mirrors
- Spherical mirrors: concave, convex

The animated ray diagrams were created by Dr. Alan Pringle.

Terms and sign conventions for lenses and mirrors

- object distance s, positive

- image distance s' ,
- positive if image is on side of outgoing light, i.e. same side of mirror, opposite side of lens: real image
- s' negative if image is on same side of lens/behind mirror: virtual image

- focal length f

  positive for concave mirror and converging lens

  negative for convex mirror and diverging lens

- object height h, positive

- image height h'

  positive if the image is upright

  negative if image is inverted

- magnification $m = h'/h$, positive if upright, negative if inverted

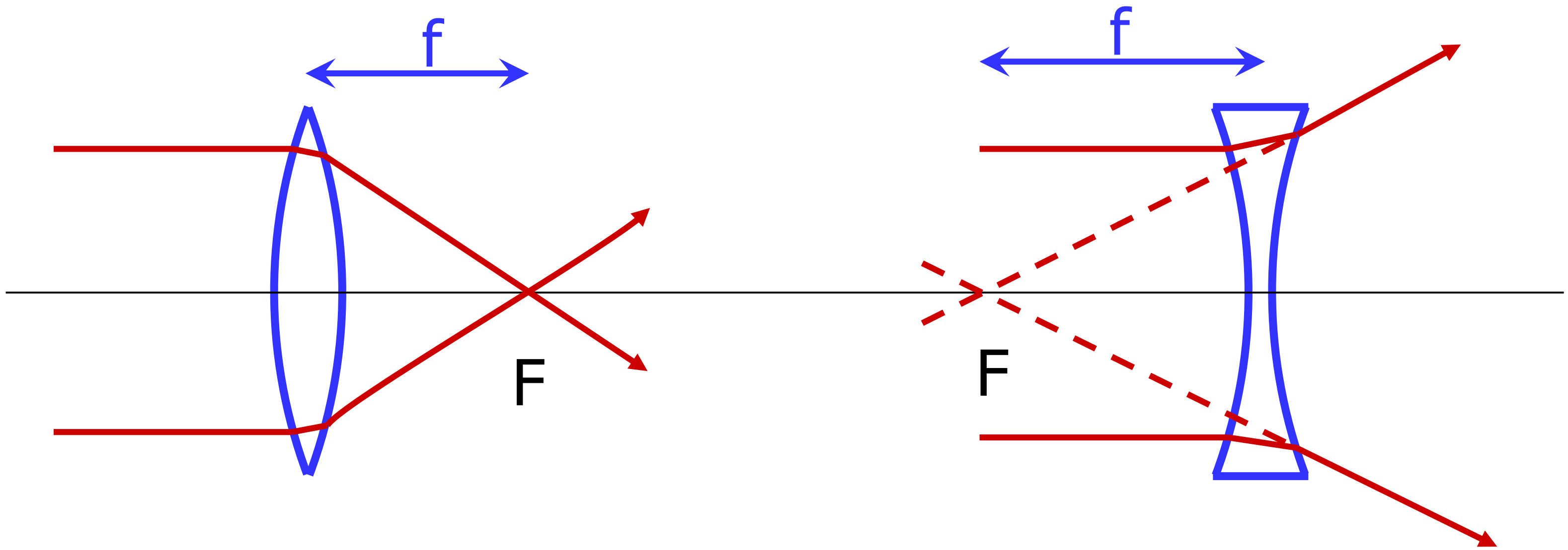
Lens equation

$$\boxed{\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}}$$

$$\boxed{m = -\frac{s'}{s} = \frac{h'}{h}}$$ magnification

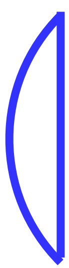
$$s' = \frac{fs}{s - f}$$

Converging and diverging lenses



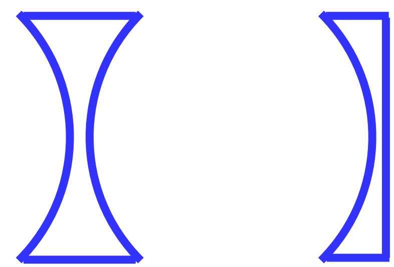
Rays refract towards optical axis

Rays refract away from optical axis



thicker in the center

thinner in the center



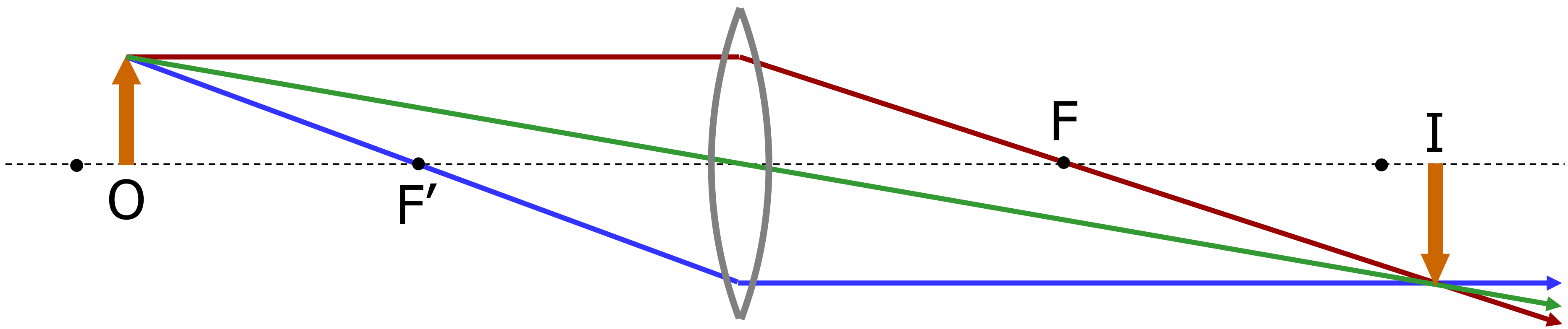
- there are focal points on both sides of each lens
- focal length f on both sides is the same

Ray diagram for converging lens

Ray 1 is parallel to the axis and refracts through F.

Ray 2 passes through F′ before refracting parallel to the axis.

Ray 3 passes straight through the center of the lens.



object between f and 2f: image is real, inverted, enlarged

object outside of 2f: image is real, inverted, reduced

object inside of f: image is virtual, upright, enlarged

Ray diagram for diverging lens

Ray 1 is parallel to the axis and refracts as if from F.

Ray 2 heads towards F′ before refracting parallel to the axis.

Ray 3 passes straight through the center of the lens.

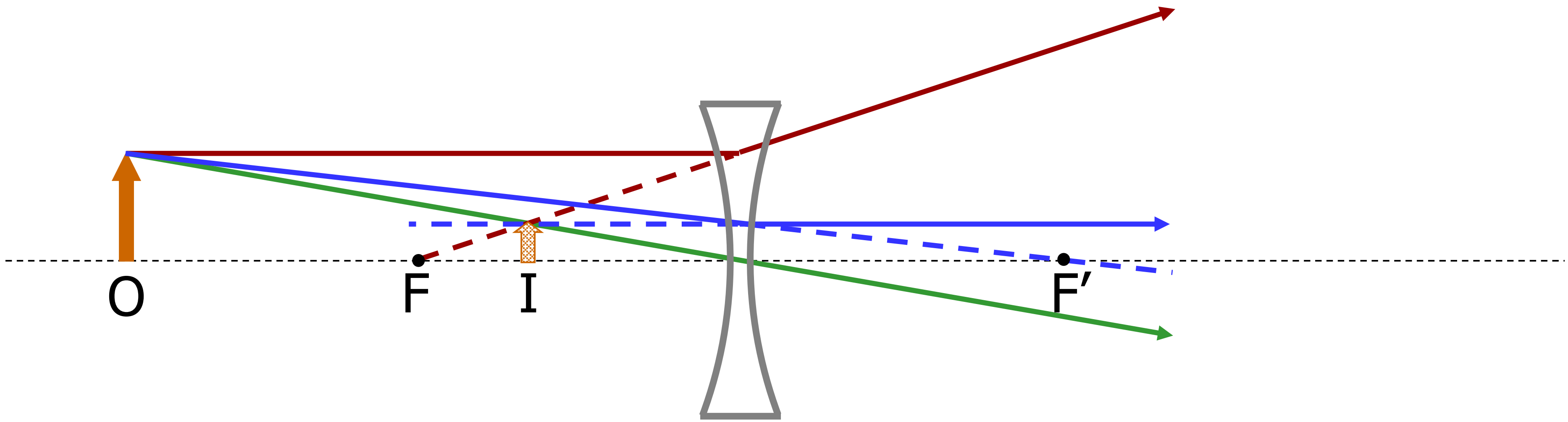
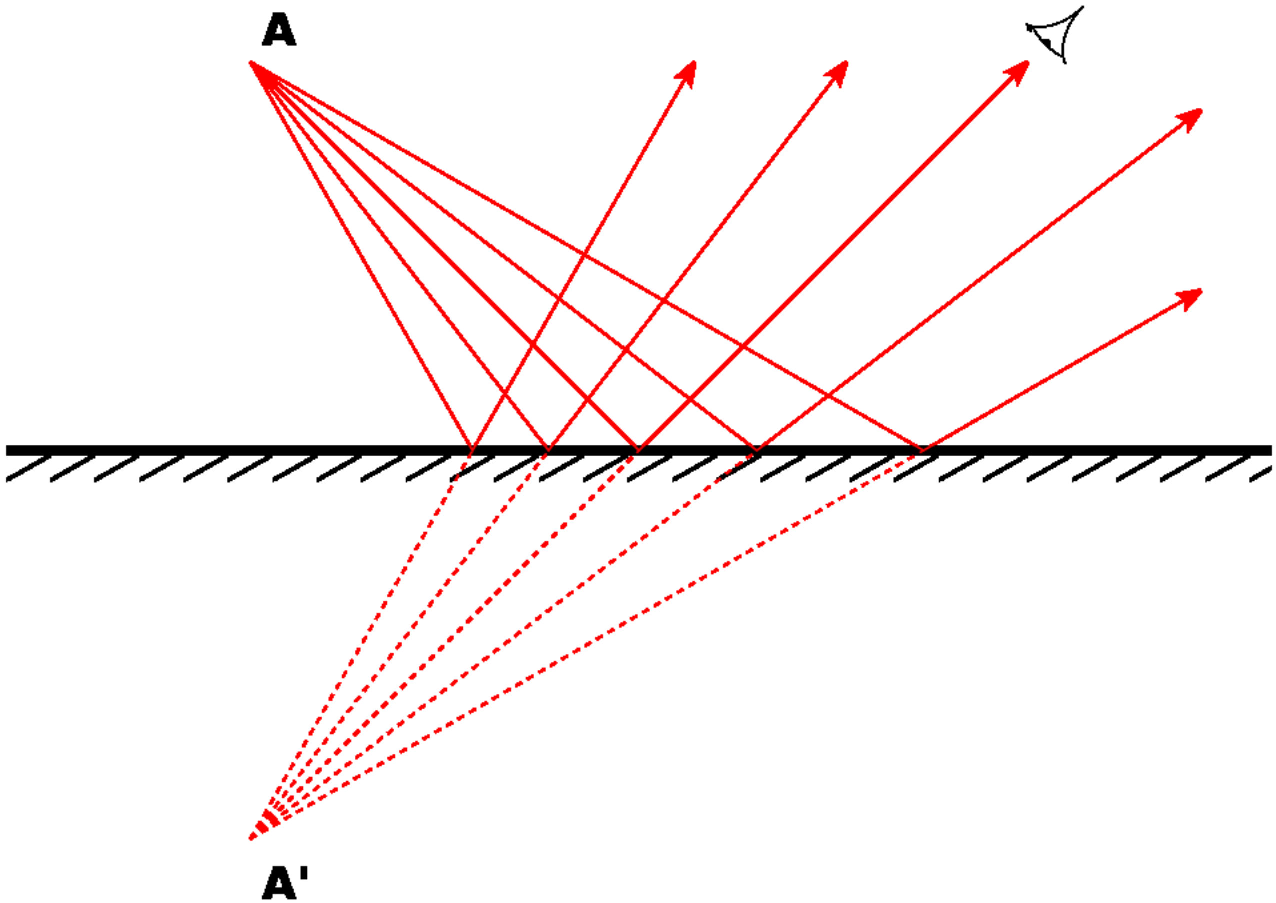


image is always virtual, upright and reduced

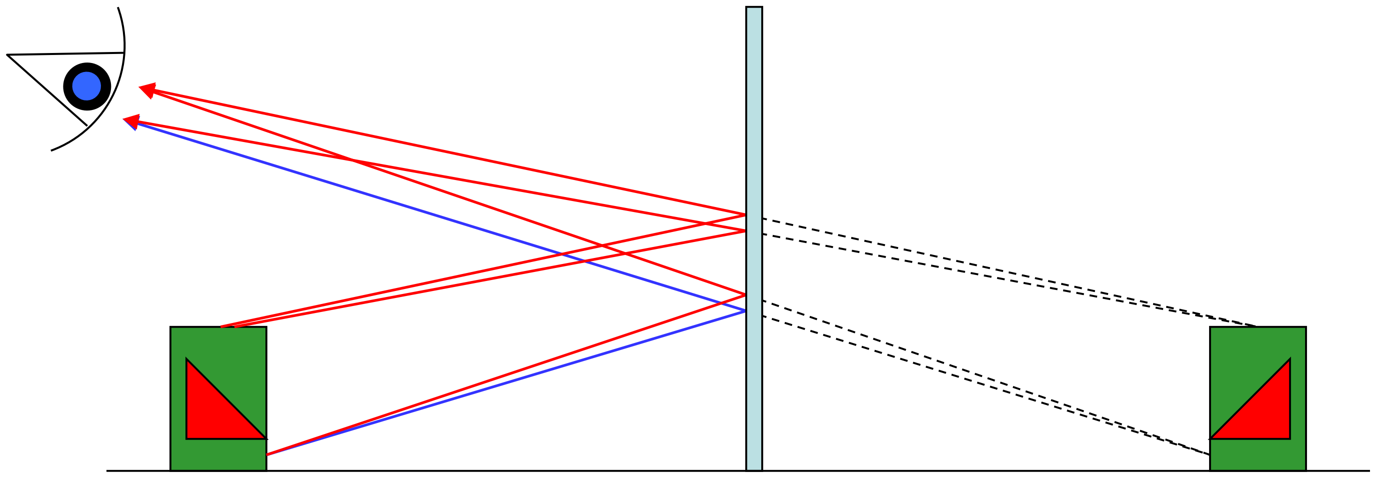
Plane mirror

- point object A, source of light



- reflected rays appear to come from A′ ⟶ A′ is image of A
- image appears to be located behind the mirror ⟶ image is **virtual**

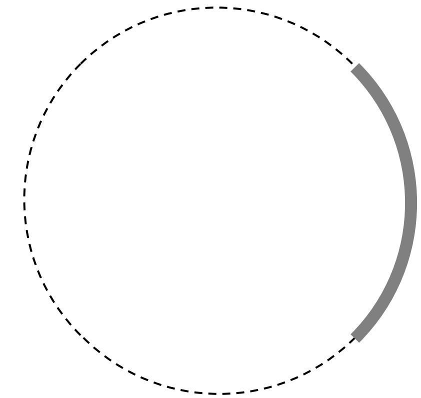
Image of an extended object



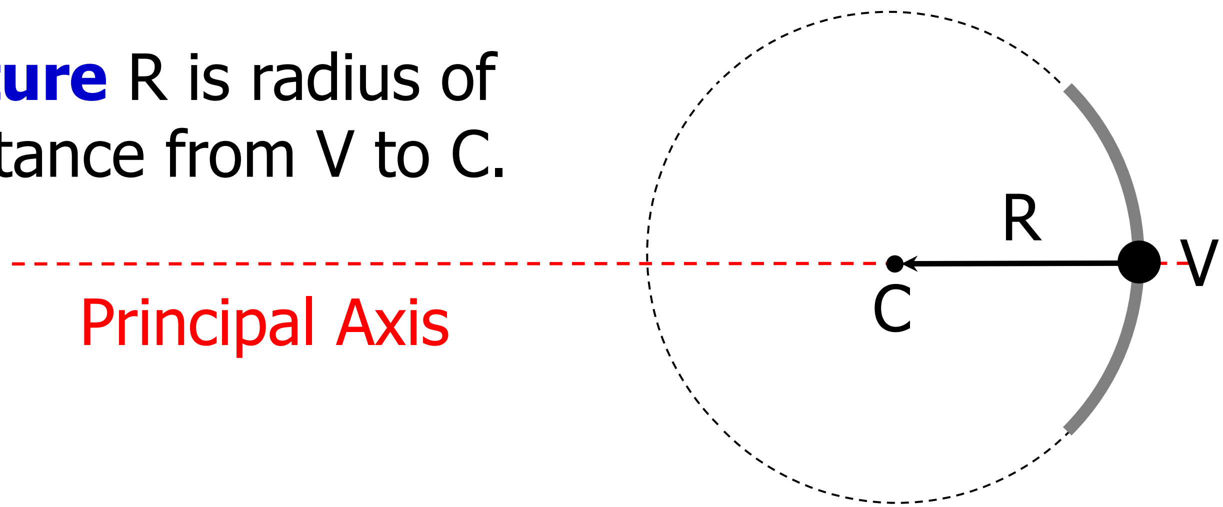
- every point of the object acts as light source
- every point has an image
- collection of image points form image of the object
- image is upright, virtual, same size as object (h’=h), s’=s

Spherical mirror

- made from (polished) sections cut from a spherical surface

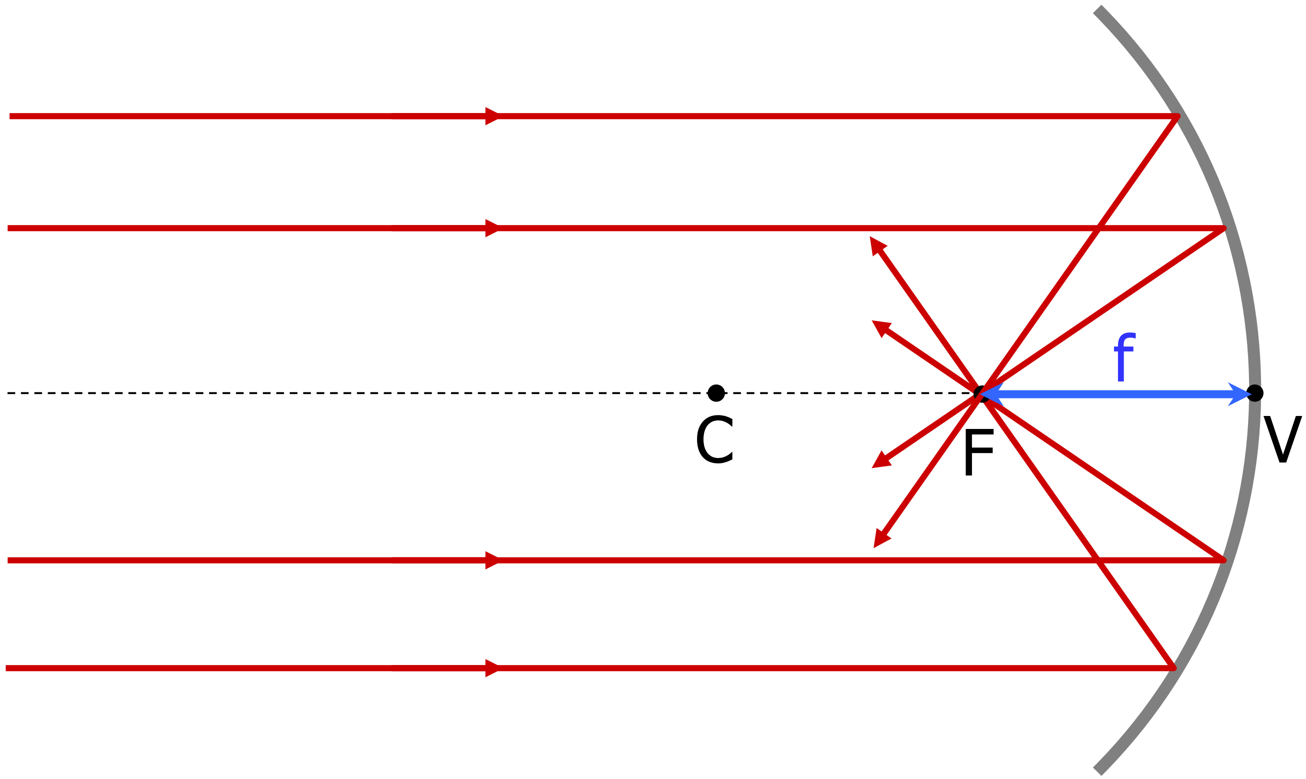


- **center of curvature** C is center of original sphere
- **vertex V** is center of mirror segment
- **radius of curvature** R is radius of sphere, or the distance from V to C.

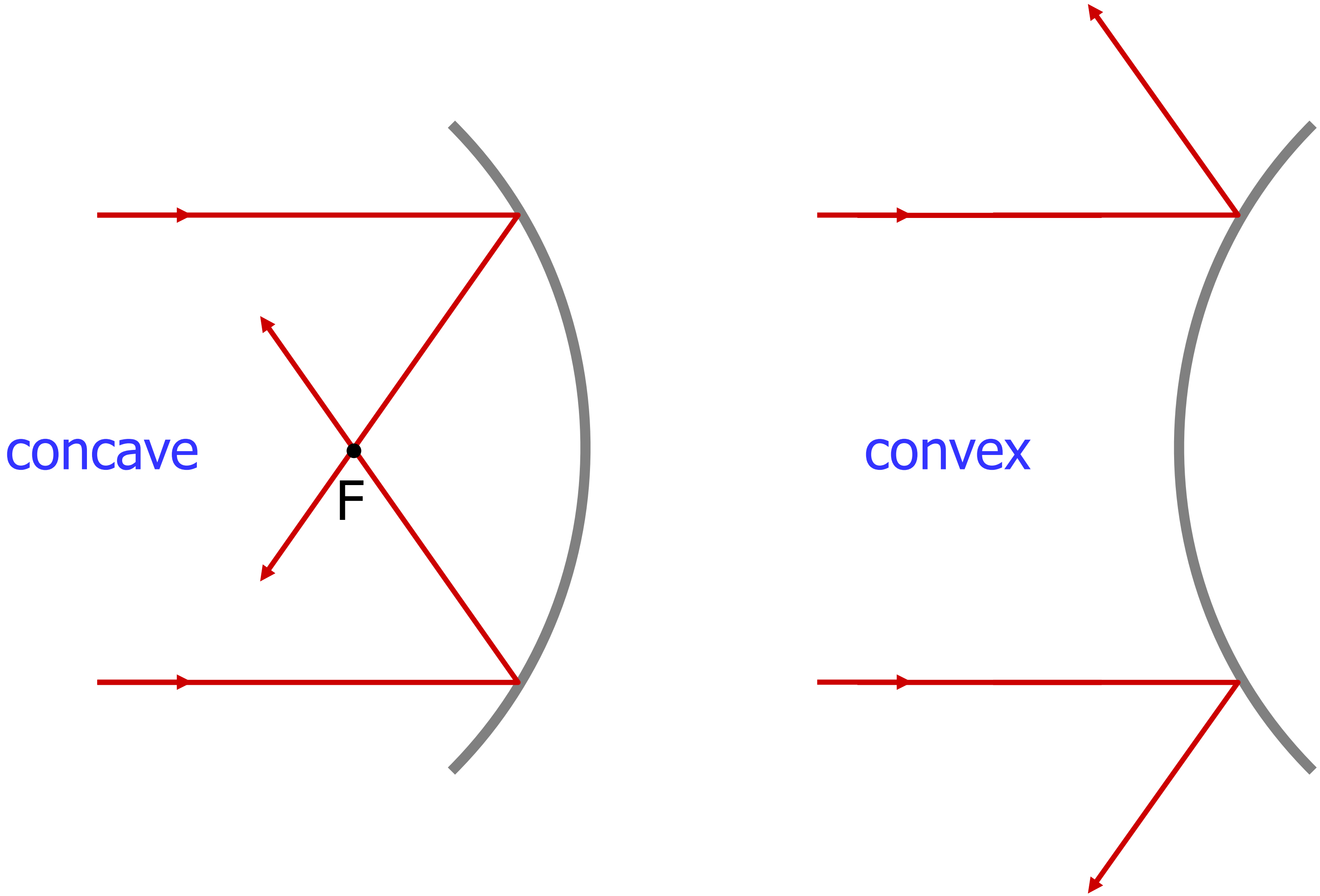


- **principal axis** (or **optical axis**) is line passing through C and V

Rays parallel to the axis get reflected through a common point the **focal point** or **focus** F.
Focal length *f* is distance from V to F.



Concave and convex mirror

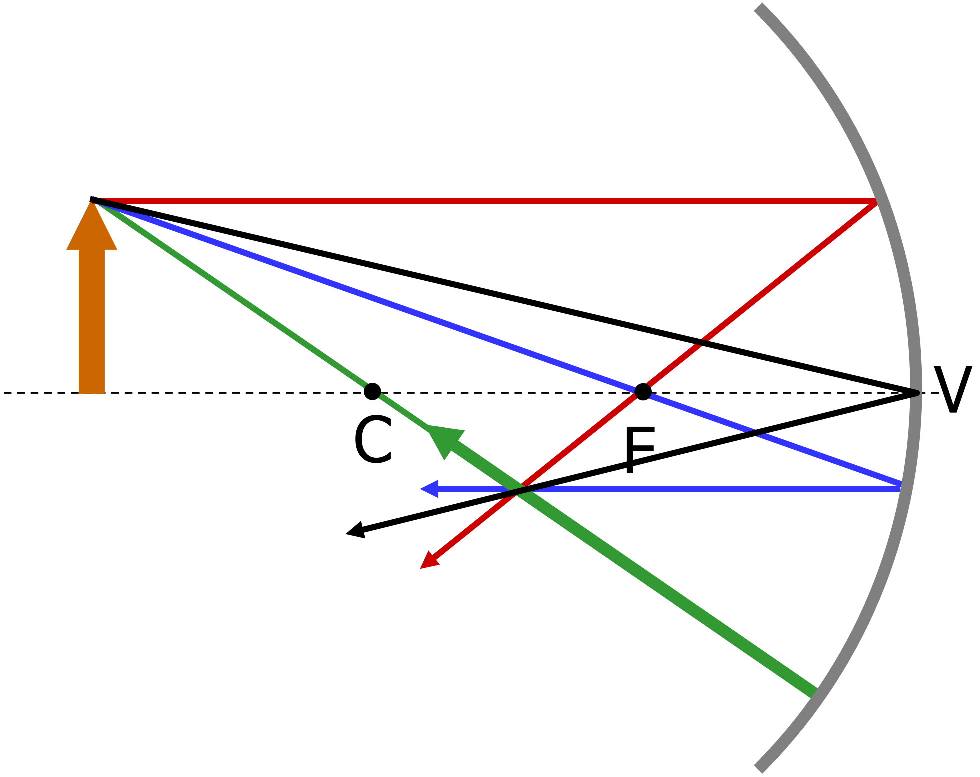


Ray diagrams

Ray 1 is parallel to the axis and reflects through F.

Ray 2 passes through F before reflecting parallel to the axis.

Ray 3 passes through C and reflects back on itself.



Ray 4 goes to the vertex V and reflects under the same angle below the optical axis

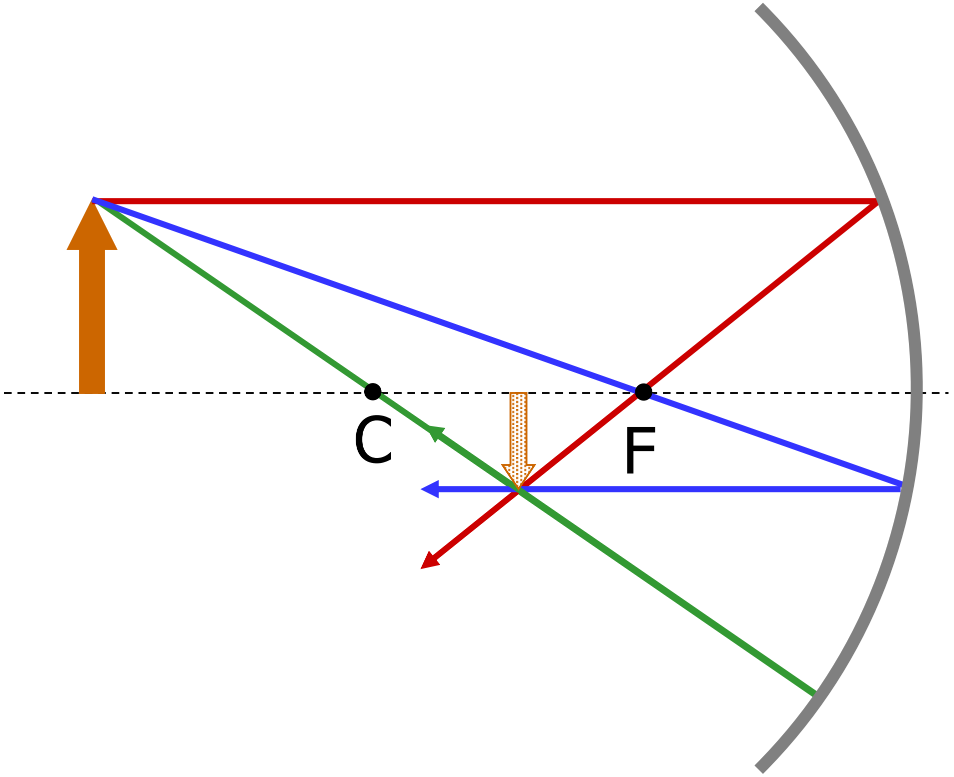
Ray Diagrams for Concave Mirrors

- image is formed where the outgoing rays cross
- two principal rays are sufficient to find image, use third and fourth to check your diagram

Example:

- object outside center (s>2f)
  $\rightarrow$ image is **real**, **inverted**, and **smaller** than object ("telescope")

- object between f and 2f
  $\rightarrow$ image is **real**, **inverted**, and **larger** than object ("microscope")



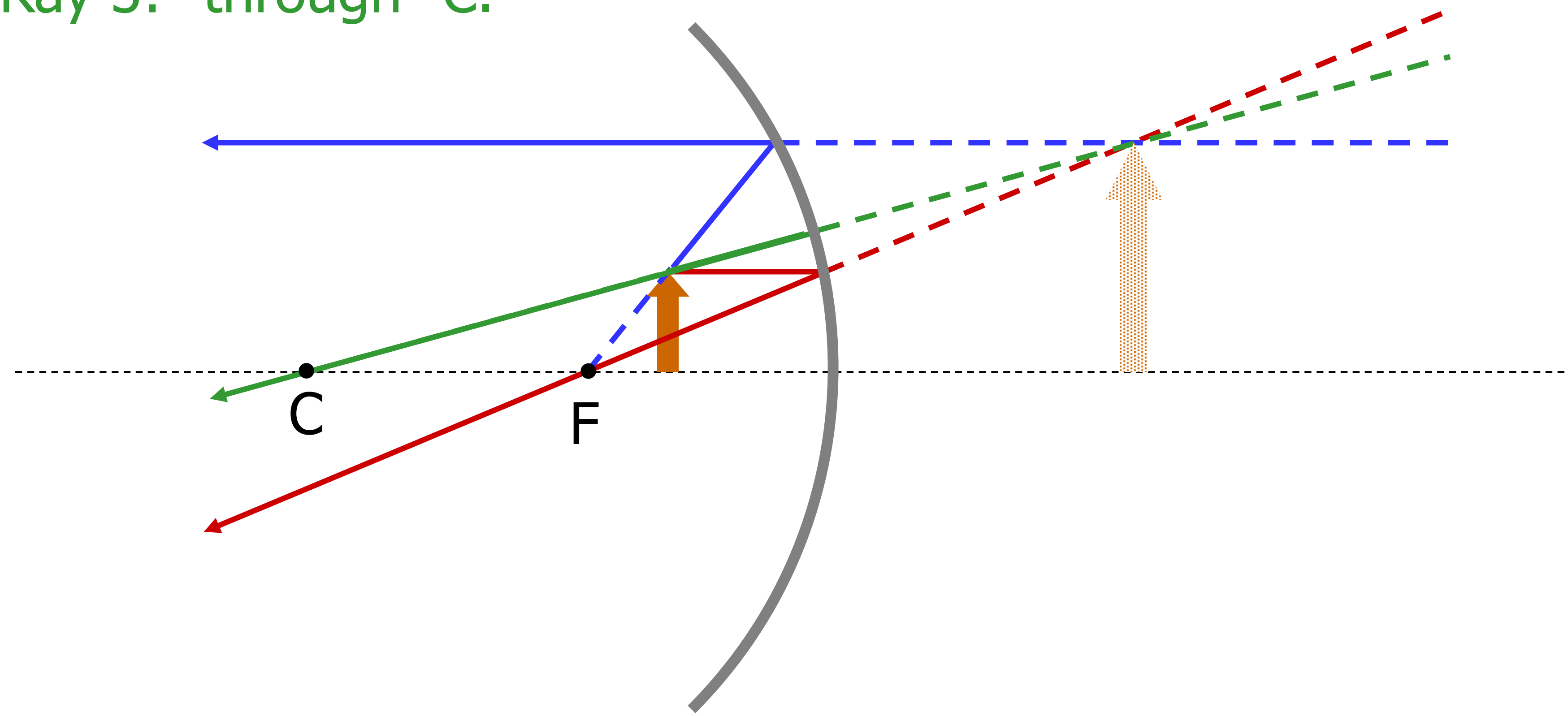
Real image: outgoing rays do cross. Can be captured on screen or by camera.

- object inside the focal point (s<f)
  → image is **virtual**, **upright**, and **larger** than object (makeup mirror)

Ray 1: parallel to the axis then through F.

Ray 2: through F then parallel to the axis.

Ray 3: "through" C.

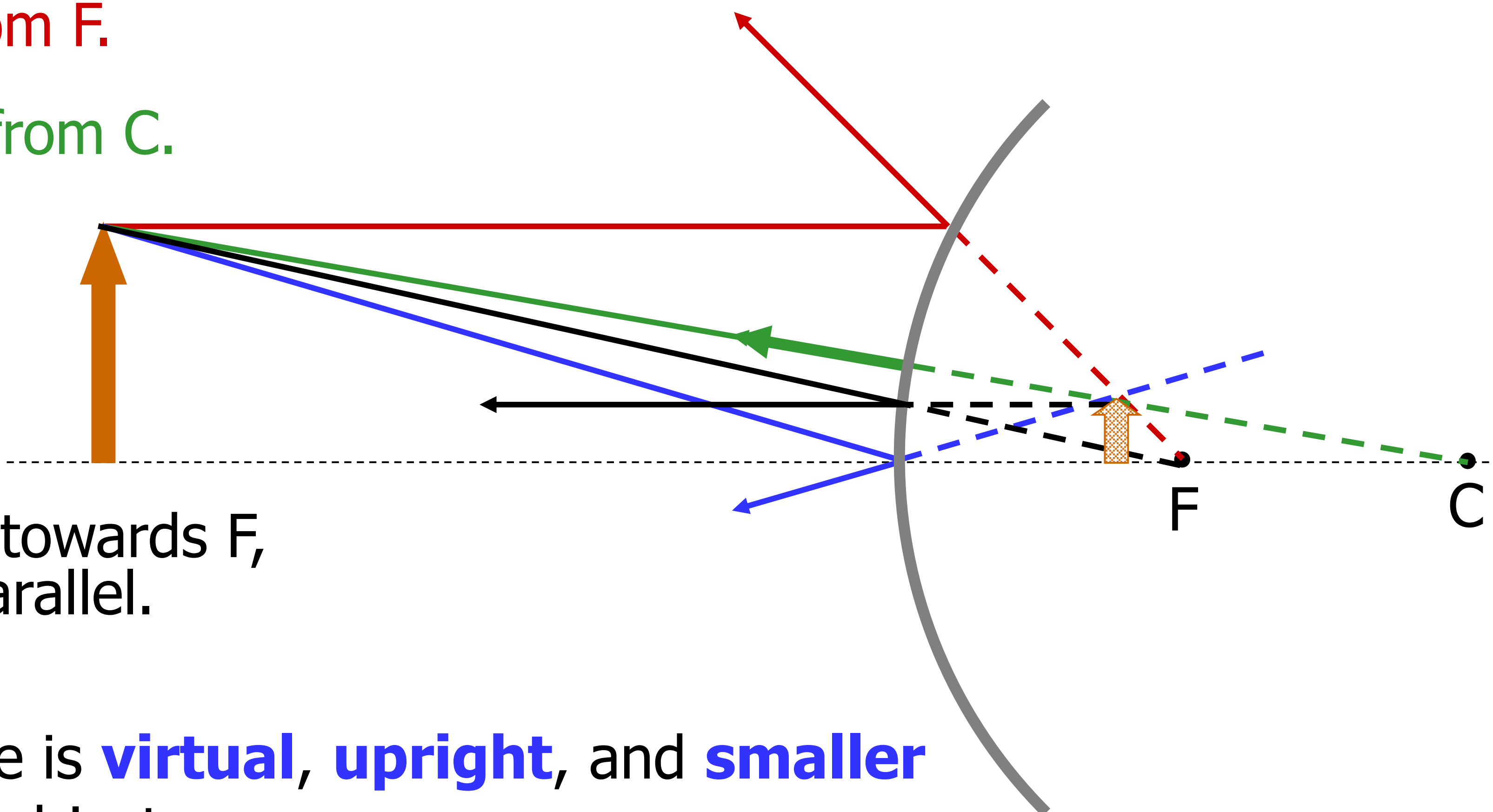


Ray Diagrams for Convex Mirrors

Ray 1: parallel to the axis then from F.

Ray 2: Vertex.

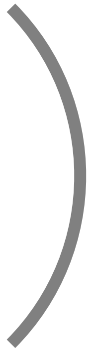
Ray 3: from C.



Ray 4: towards F, then parallel.

- image is **virtual**, **upright**, and **smaller** than object

Concave mirrors:



Shaving and makeup mirrors
Solar cookers
Satellite dishes (for EM waves)

Convex mirrors:

Passenger side rear-view mirrors
Anti-shoplifting (surveillance) mirrors
Christmas tree ornaments

Image formation for mirrors and lenses

Type	Focal length f	Object distance s	Image distance s’	Character	Orientation	Size
Concave mirror/ Converging lens	$f > 0$	$s > 2f$	$f < s' < 2f$	real	inverted	reduced
		$f < s < 2f$	$s' > 2f$	real	inverted	enlarged
		$s<f$	$s'<0$	virtual	upright	enlarged
Convex mirror/ diverging lens	$f < 0$	$s > 0$	$s' < 0$	virtual	upright	reduced

Do not memorize! We can easily get this from the equation!