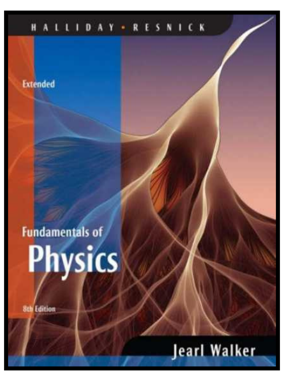
University Physics II



Week 9 : Day 3

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Outline

- **Double-slit Interference**
  - Young's experiment
  - Locating diffraction min/max
- **Diffraction gratings**
  - Defining dispersion
  - Measuring resolving power
- **Activity – Laboratory #3**
  - Double-Slit Experiment – Wavelength calculation
  - Measuring with Interference and Diffraction

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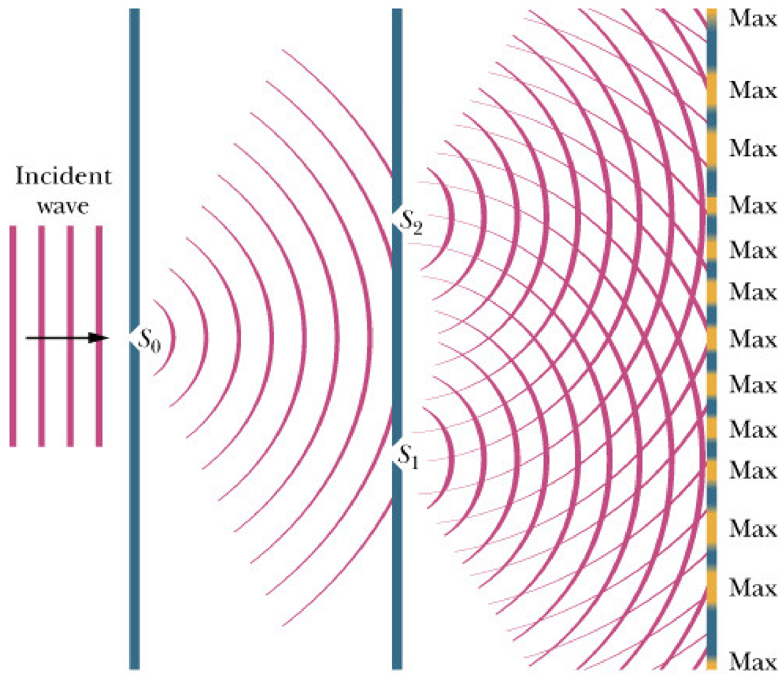
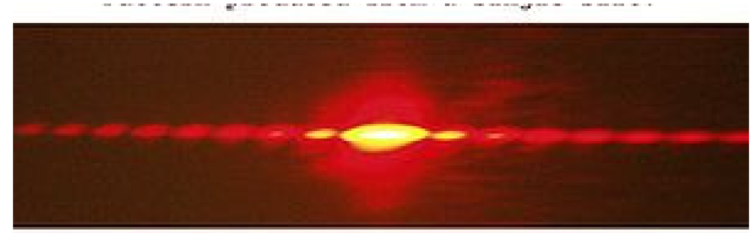
Young's Experiment

For waves entering two slits, the emerging waves interfere and form an interference (diffraction) pattern:

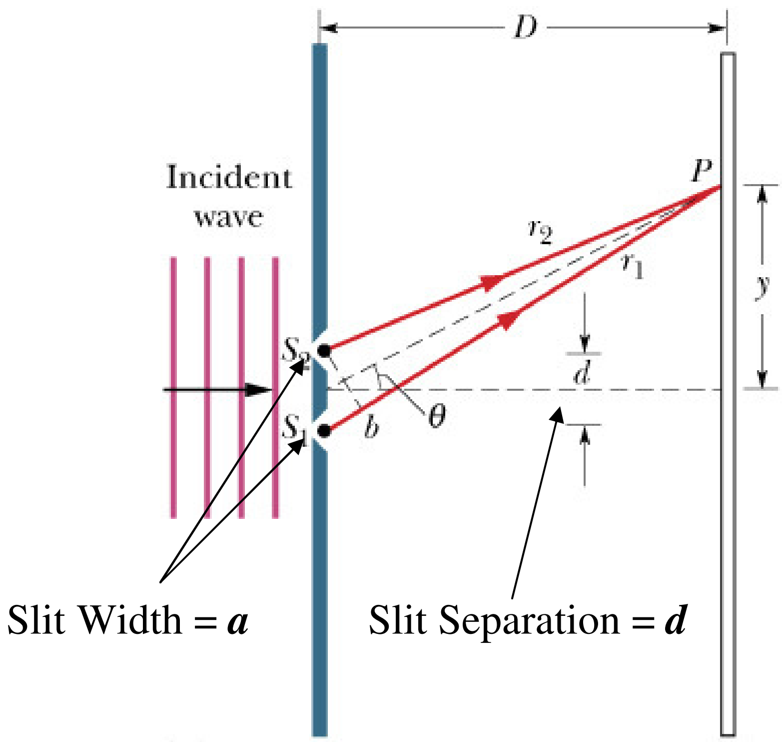


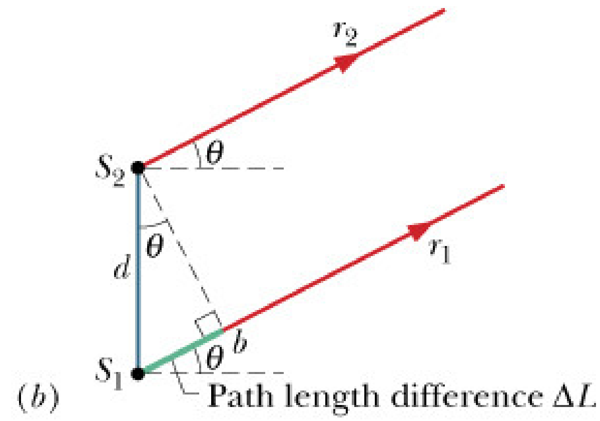


Pattern produced from a double slit.

Double-Slit Diffraction Fringes

What appears at each point on the screen is determined by the path length difference ΔL of the rays reaching that point.





Path Length Difference:

$$\Delta L = d \sin\theta$$

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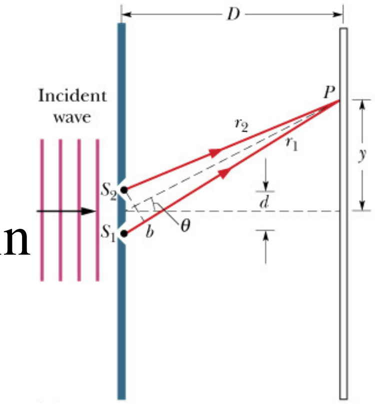
Intensity in Double-Slit Interference

Minima when: $\frac{1}{2}\phi = \left(m + \frac{1}{2}\right)\pi$

$\rightarrow d\sin\theta = \left(m + \frac{1}{2}\right)\lambda$ for $m = 0, 1, 2, \ldots$ (minima)

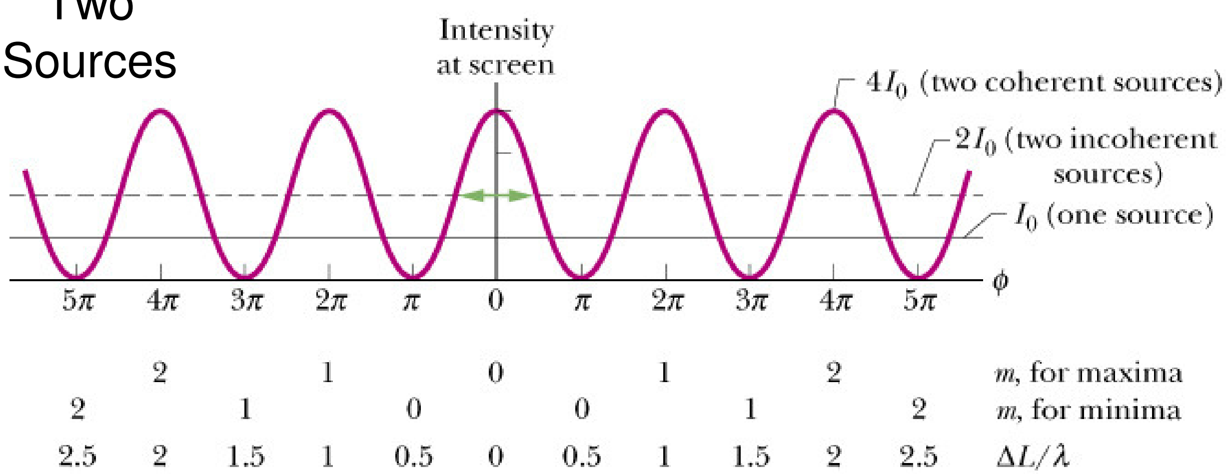
Maxima when: $\frac{1}{2}\phi = m\pi$ for $m = 0, 1, 2, \ldots \rightarrow \phi = 2m\pi = \frac{2\pi d}{\lambda}\sin$



$\rightarrow d\sin\theta = m\lambda$ for $m = 0, 1, 2, \ldots$ (maxima)

$E_1 = E_0 \sin\omega t$ and $E_2 = E_0 \sin(\omega t + \phi)$

Two Sources



Phase Difference $\phi = \frac{2\pi d}{\lambda}\sin\theta$

$$I_{avg} = 2I_0$$

$$I = 4I_0\cos^2\tfrac{1}{2}\phi$$

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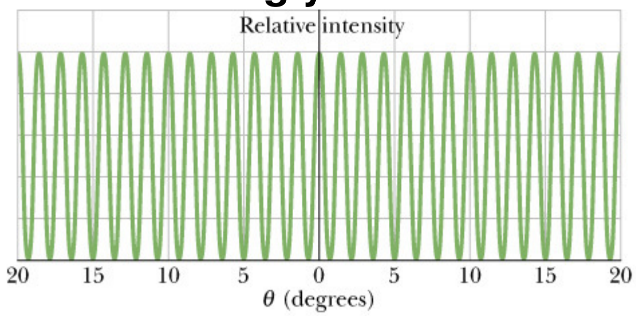
Diffraction by a Double Slit

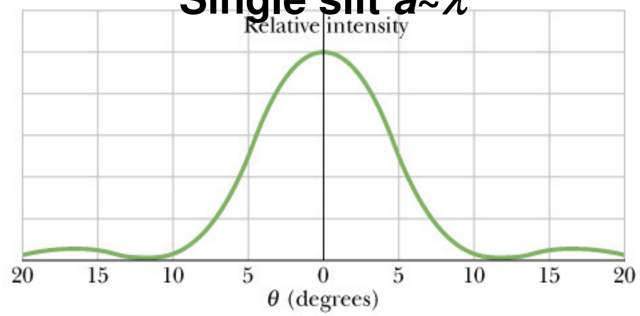
In the double-slit experiment we assume that the slit width $a<<\lambda$.
If this is not the case then the observed pattern changes:

Two vanishingly narrow slits $a<<\lambda$



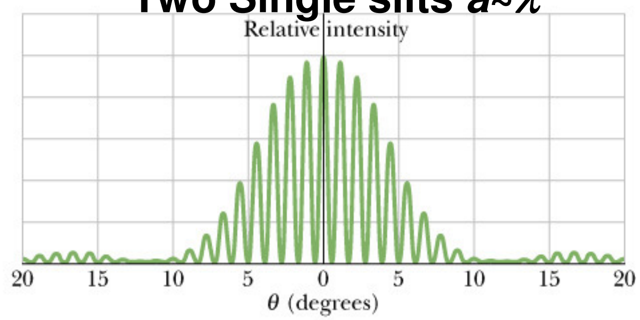
(a)

Single slit $a\sim\lambda$



(b)

Two Single slits $a\sim\lambda$



(c)

We observe diffraction from both!

$$I(\theta) = I_m \left(\cos^2 \beta\right)\left(\frac{\sin\alpha}{\alpha}\right)^2 \quad \text{(double slit)}$$

$$\beta = \frac{\pi d}{\lambda}\sin\theta \qquad \alpha = \frac{\pi a}{\lambda}\sin\theta$$

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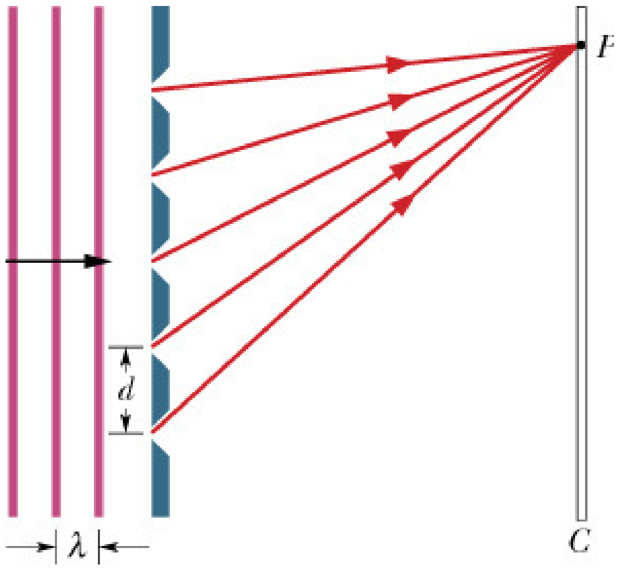
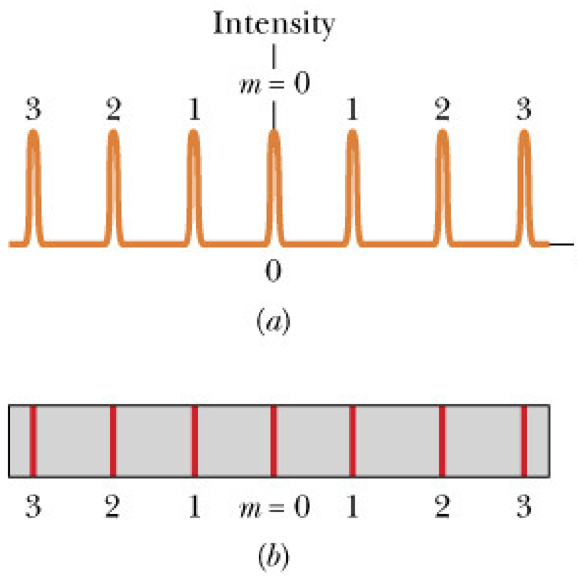
Diffraction Gratings

A device with *N* slits (rulings) can be used to manipulate light, such as separate different wavelengths of light that are contained in a single beam. How does a diffraction grating affect monochromatic light?





$$d \sin\theta = m\lambda \quad \text{for } m = 0, 1, 2\ldots \quad \text{(maxima-lines)}$$

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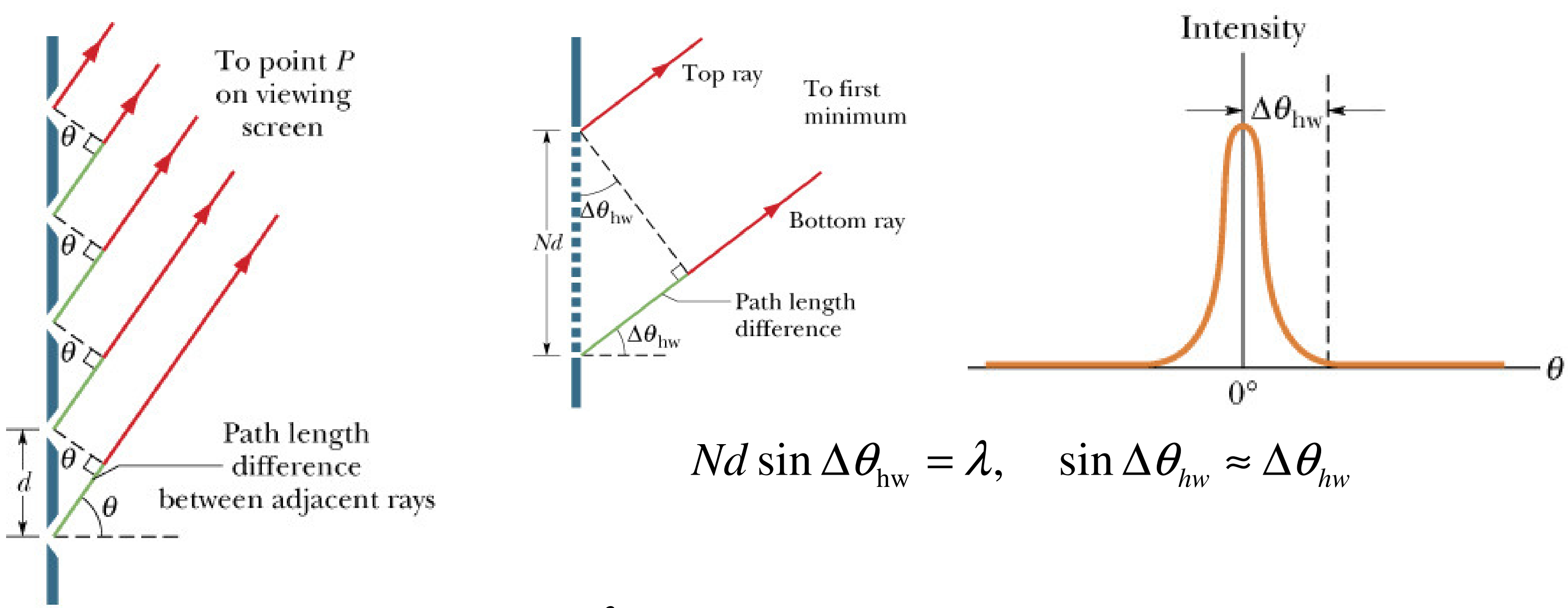
Width of Lines & Intensity

The ability of the diffraction grating to resolve (separate) different wavelengths depends on the width of the lines (maxima).



$$Nd\sin\Delta\theta_{\mathrm{hw}} = \lambda, \quad \sin\Delta\theta_{hw} \approx \Delta\theta_{hw}$$

$$\Delta\theta_{\mathrm{hw}} = \frac{\lambda}{Nd\cos\theta} \ \text{(half width of line at } \theta\text{)}$$

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Dispersion and Resolving Power in Gratings

Dispersion is the angular spreading of different wavelengths by a grating:

$$D = \frac{\Delta\theta}{\Delta\lambda} \quad \text{(dispersion defined)}$$

$$\Rightarrow \boxed{D = \frac{m}{d\cos\theta} \quad \text{(dispersion of a grating)}}$$

$$D = \frac{1}{d\lambda/d\theta} = \frac{d\theta}{d\lambda}$$

$$\Rightarrow [D] = m^{-1}$$

$\Downarrow$

The wavenumber, *k* is an intrinsic measure of the dispersion of a wave

Resolving Power:

$$R = \frac{\lambda_{\text{avg}}}{\Delta\lambda} \quad \text{(resolving power defined)}$$

$$\Rightarrow \boxed{R = Nm \ \text{(resolving power of a grating)}}$$

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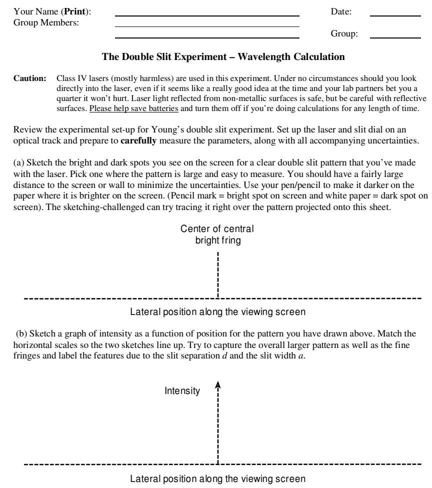
Activity – Laboratory # 3

- **The Double-Slit Experiment**
  - Activity – Wavelength Calculation
    - *Examine Parameters*
      - Slit width, *a*
      - Slit separation, *d*
    - Determine wavelength
  - *Activity - Measuring with Interference and diffraction*
    - Calibration
      - *Methods I – Single Slit*
      - ~~*Method II – Double-Slit*~~
      - *Method III - Grating*
    - Width of Human Hair



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Group Members: ____________
____________ Group: ______

The Double Slit Experiment – Wavelength Calculation

Caution: Class IV lasers (mostly harmless) are used in this experiment. Under no circumstances should you look directly into the laser, even if it seems like a really good idea at the time and your lab partners bet you a quarter it won't hurt. Laser light reflected from non-metallic surfaces is safe, but be careful with reflective surfaces. Please help save batteries and turn them off if you're doing calculations for any length of time.

Review the experimental set-up for Young's double slit experiment. Set up the laser and slit dial on an optical track and prepare to **carefully** measure the parameters, along with all accompanying uncertainties.

(a) Sketch the bright and dark spots you see on the screen for a clear double slit pattern that you've made with the laser. Pick one where the pattern is large and easy to measure. You should have a fairly large distance to the screen or wall to minimize the uncertainties. Use your pen/pencil to make it darker on the paper where it is brighter on the screen. (Pencil mark = bright spot on screen and white paper = dark spot on screen). The sketching-challenged can try tracing it right over the pattern projected onto this sheet.

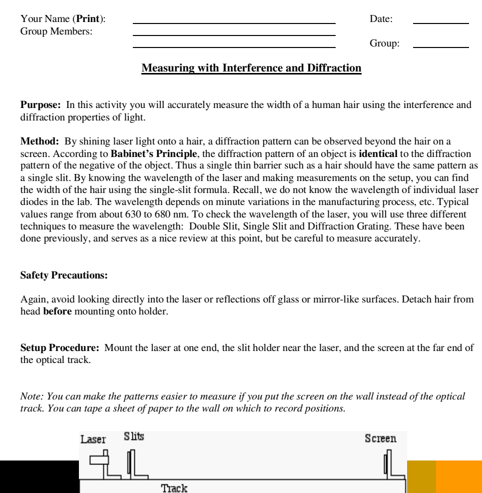
Center of central bright fring

Lateral position along the viewing screen

(b) Sketch a graph of intensity as a function of position for the pattern you have drawn above. Match the horizontal scales so the two sketches line up. Try to capture the overall larger pattern as well as the fine fringes and label the features due to the slit separation *d* and the slit width *a*.

Intensity

Lateral position along the viewing screen



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Measuring with Interference and Diffraction

Purpose: In this activity you will accurately measure the width of a human hair using the interference and diffraction properties of light.

Method: By shining laser light onto a hair, a diffraction pattern can be observed beyond the hair on a screen. According to **Babinet's Principle**, the diffraction pattern of an object is **identical** to the diffraction pattern of the negative of the object. Thus a single thin barrier such as a hair should have the same pattern as a single slit. By knowing the wavelength of the laser and making measurements on the setup, you can find the width of the hair using the single-slit formula. Recall, we do not know the wavelength of individual laser diodes in the lab. The wavelength depends on minute variations in the manufacturing process, etc. Typical values range from about 630 to 680 nm. To check the wavelength of the laser, you will use three different techniques to measure the wavelength: Double Slit, Single Slit and Diffraction Grating. These have been done previously, and serves as a nice review at this point, but be careful to measure accurately.

Safety Precautions:

Again, avoid looking directly into the laser or reflections off glass or mirror-like surfaces. Detach hair from head **before** mounting onto holder.

Setup Procedure: Mount the laser at one end, the slit holder near the laser, and the screen at the far end of the optical track.

Note: You can make the patterns easier to measure if you put the screen on the wall instead of the optical track. You can tape a sheet of paper to the wall on which to record positions.

Laser
Slits
Screen
Track

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