Experiment 3. Understanding Optical Interference

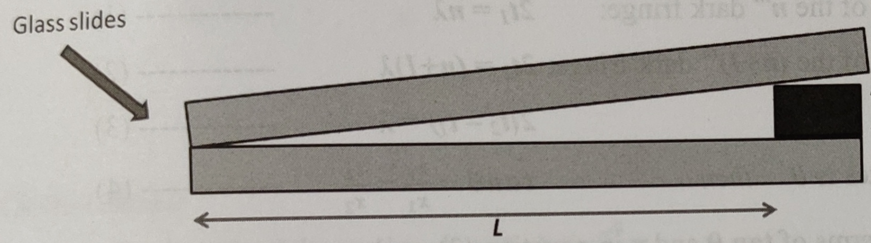
Aim: To calculate the thickness of a thin paper by forming interference fringes using an air wedge arrangement.

Objective:

i. To understand the phenomenon of the interference
ii. To understand how coherent light sources can be produced

About the experiment / Theoretical background:

A thin film having zero thickness at one end and *progressively* increasing to a particular thickness at the other end is called a wedge. A thin wedge of air film can be formed by two glass slides on each other at one edge and separated by a thin spacer at the opposite edge (See Fig).

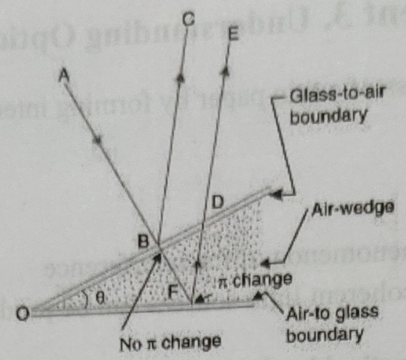


The wedge angle is usually very small and of the order of a degree. When a parallel beam of monochromatic light illuminates the wedge from above, the rays reflected from the two bounding surfaces of the film are not parallel they appear to diverge from a point near the film. When light is incident on the wedge from above, it gets partly reflected from the glass to air boundary at the top of the air film and the other part of the light is transmitted through the air film and gets reflected at the air to glass inter layer. These rays interfere constructively or destructively producing alternate bright and dark fringes.

The path difference between the two rays is $(2t + \frac{\lambda}{2})$, where t is the air film thickness. The term $\frac{\lambda}{2}$ arises due to the fact that the reflection from the air glass boundary is reflection from a denser medium producing a shift of $\frac{\lambda}{2}$ in the path of the ray.

The condition for obtaining a dark fringe is $2t + \frac{\lambda}{2} = (2n+1)\frac{\lambda}{2}$, which simplifies to $2t = n\lambda$.

The condition for obtaining a bright fringe is $2t + \frac{\lambda}{2} = n\lambda$



Derivation of an expression for the thickness of the spacer

Let x_1 and x_2 be distances of the positions of the n^{th} and $(n+1)^{th}$ dark fringes from the end where the glass plates are in contact and t_1 and t_2 are the air film path in the wedge respectively.

Condition for the formation of the n^{th} dark fringe: $2t_1 = n\lambda$ ------------- (1)

Condition for the formation of the $(n+1)^{th}$ dark fringe: $2t_2 = (n+1)\lambda$ ------------- (2)

Thus, $2(t_2 - t_1) = \lambda$ ------------- (3)

If the angle between the plates is θ then $\tan\theta = \frac{t_1}{x_1} = \frac{t_2}{x_2}$ ------------- (4)

Substituting for t_1 and t_2 in terms of **tan θ** and x in equation (3) we have

$$2(x_2 - x_1)\tan\theta = \lambda \quad \text{------------- (5)}$$

However, $(x_2 - x_1)$ is the fringe width β. Equation 5 now becomes

$$2\,\beta\,\tan\theta = \lambda \quad \text{------------- (6)}$$

If d is the thickness of the spacer and L is the length of the wedge then

$$\tan\theta = \frac{d}{L}$$

Thus, equation (6) can be written as $2\beta\frac{d}{L} = \lambda$

From which the thickness of the object can be written as $d = \frac{\lambda L}{2\beta}$ ------------- (7)

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Procedure: (write in your own words)

Take a sodium vapour lamp, which is a monochromatic source of light and a travelling microscope used to measure fringe width, inclined glass plate used to make light fall on glass plate.

Introduce the glass plates having paper into the

reflecting glass plate system.
Place the glass plates exactly below the inclined glass plate. Look down normally and adjust the angle of glass plate till you see the reflection of sodium vapour light. Introduce the travelling microscope such that the objective lens of the microscope is placed exactly on top of the reflection. Adjust for the horizontal tilt such that the fringes are in full view. Focus the microscope for sharp fringes.
Bring the cross wire on a dark fringe, record the reading using magnifying glass, note main scale & vernier scale reading. Note down alternate dark fringe reading. Take reading till 18^{th} dark fringe.

Observations:

1. Effective length of the wedge, L = 2.3×10^{-2} m
2. Wavelength of the sodium vapor lamp = 5893×10^{-10} m
3. Least count of the travelling microscope = $\frac{\text{(Value of 1 MSD)}}{\text{No.of divisions on vernier}} = \frac{0.05}{50} = 0.001\text{cm}$

Observation Table:

Dark Fringe number N	Travelling Microscope Reading (R)		
	MSR	CVD	TR = MSR + (CVD X LC)(cm)
0	11.9	20	11.92
2	12.05	10	12.06
4	12.05	20	12.07
6	12.1	20	12.12
8	12.1	35	12.135
10	12.15	10	12.16
12	12.15	35	12.185
14	12.2	10	12.21
16	12.25	0	12.25
18	12.25	20	12.27

Calculation:

Thickness of the given paper $d = \frac{\lambda L}{2\ slope}$

$$\text{Slope} = \beta = \frac{3.5 \times 0.02}{2.8 \times 2} = 0.0125$$

Thickness of the given paper, $d = \frac{\lambda L}{2\beta}$

$$= \frac{5893 \times 10^{-10} \times 2.3 \times 10^{-2}}{2 \times 1.25 \times 10^{-2}}$$

$$= 5421.56 \times 10^{-10}\ m$$

$$= 0.5421\ \mu m$$

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Results and conclusions:

$\therefore$ The thickness of the given paper is 5.421×10^{-7} m.

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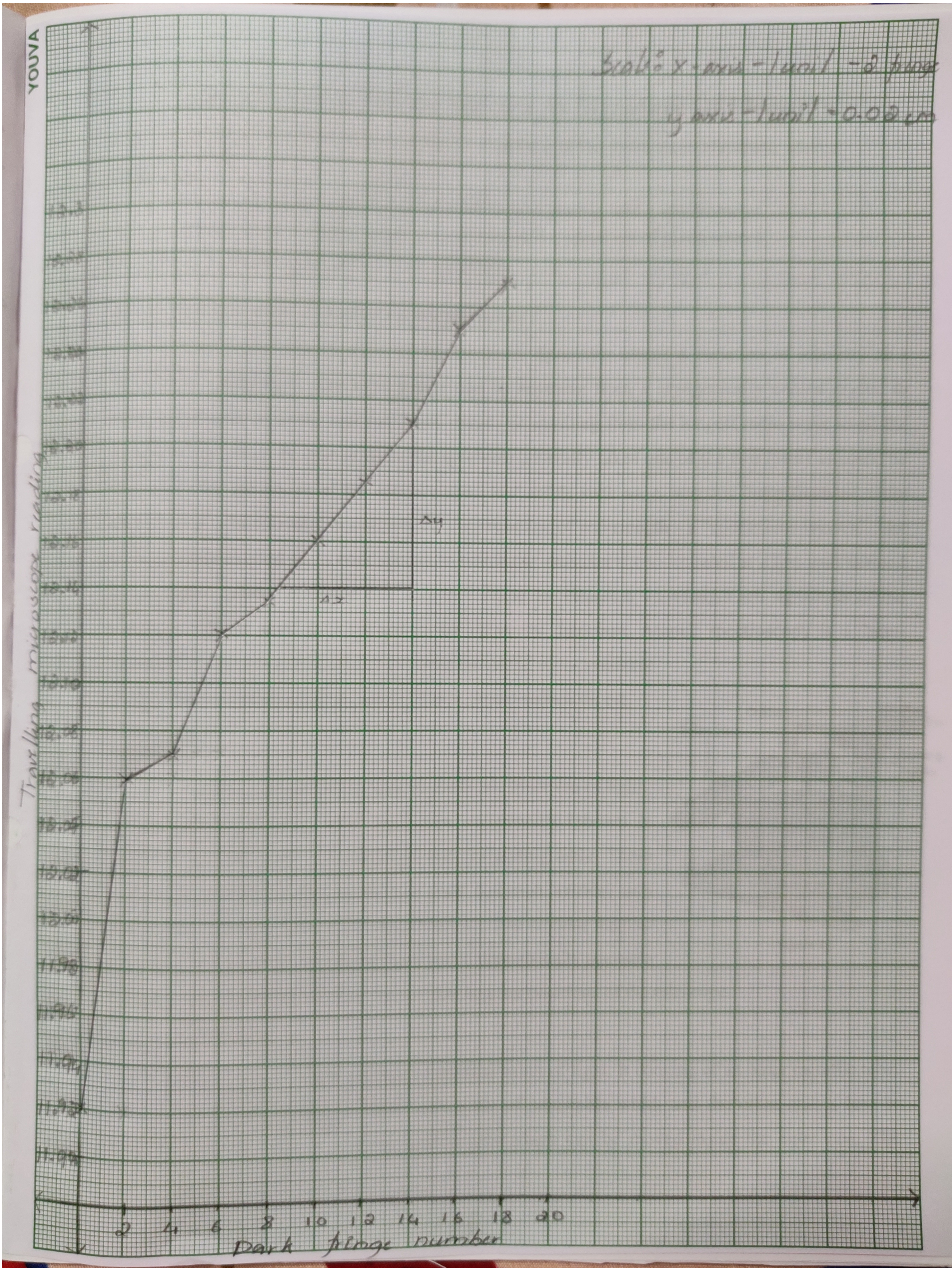


YOUVA
Scale: x-axis - 1unit - 2 fringe
y axis - 1unit - 0.02 cm
Travelling microscope reading
Δy
Δx
2
4
6
8
10
12
14
16
18
20
Dark fringe number

Experiment 4. Atomic Spectra As Signature Of Elements

Aim: To determine the wavelength of atomic transition in the given monochromatic source.

Objectives:

i. To become familiar with the use of a diffraction grating and a spectrometer
ii. To measure the wavelengths of certain lines in the spectrum of given source.
iii. Analyze the spectrum of different elements.

About the experiment / Theoretical background:

Any light source is characterized by its spectrum. Spectrum means a variation of intensity as a function of wavelength. The light source can be anything from a cryogenically cooled crystal to super hot plasma or a star, and the "light" might be anything from the longest radio wave to all the way down to γ-rays. In case of light, the spectrum generally takes one of the two forms as could be seen from the slit image of the spectrometer: Hot solids such as, a tungsten lamp filament emits spectra where the intensity is a slowly varying function of wavelength - a "continuous spectra". Hot or electrically excited gases emit spectra in which the emission is concentrated at a few well defined wavelengths- called "emission line spectra". These are emission wavelength are signatures of the elements and are used as a technique for elemental detection. Atomic spectroscopy is a "non-invasive" technique and is one of the most powerful tools available to physicists studying plasmas, stars, flames, semiconductors, etc.

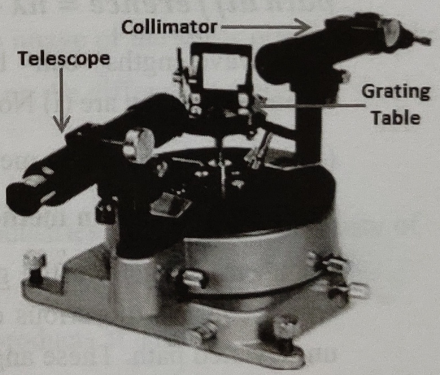


Figure 1.

Spectrometer:

A spectrometer is an instrument used to study the spectrum of light.
A spectrometer consists of three major components (shown in figure1.): (a) collimator, (b) telescope and (c) grating table. These can be independently moved around their common vertical axis passing through the center of the spectrometer. The circular angular scale together with two vernier scales located diametrically opposite to each other (180° off), enables one to read angular positions of the telescope..

Collimator

Collimator is a device which produces a parallel beam of light. It consists of an outer metallic tube. One end of the outer tube is fitted with a slit of adjustable width and the other end, a lens is mounted with the help of another coaxial tube which can be moved inside the outer one. The separation between the lens and slit can be adjusted by moving the inner tube with the help of a knob. The slit is illuminated by a source under inspection. If the separation between the lens and slit is equal to the focal length, then slit acts as a source of light placed at the focus of the lens.

Grating table

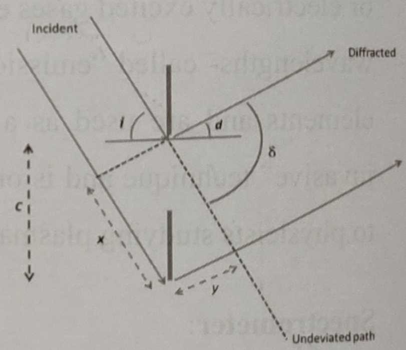
Grating table is used to place the dispersive element like grating which can disperse the different wavelength in different directions. The height and the orientation of this table can be adjusted with respect to the collimator axis for the proper mounting of grating.

Telescope

The telescope is used to detect the light. It can be rotated about an axis perpendicular to the plane of the grating table and passing through the centre of the table. The angular position of the telescope can be recorded with the help of two circular scales. The axis of the collimator and telescope lies in same horizontal plane.

Theory:

The grating can be considered as a large number (N) of equally spaced very narrow slits with slit separation C. For light of wavelength λ, a principal maximum occurs when the path difference between neighboring rays is an integer multiple of λ.



$$path\ difference = n\lambda \text{ ------------- (1)}$$

The wavelengths can be measured using two different techniques. They are (i) Normal incidence method and (ii) Minimum deviation method.

Minimum deviation method:

Light emerging from the grating in the normal incidence method, will form a diffraction pattern which consists of various colours appearing at various angles. The angles are measured from the un-deviated path. These angles are also called as the angle of deviation. If the angle of incidence is now increased continuously then it is found that the angle of deviation first decreases reaches a minimum and then increases again. If θ is the angle of minimum deviation, then for constructive superposition we have, $2CSin\left(\frac{\theta}{2}\right) = n\lambda$

Consider a diffraction grating with slit separation of $\boldsymbol{c}$ as shown in the figure. Let $\boldsymbol{i}$ be the angle of incidence and $\boldsymbol{d}$ be the angle of diffraction. The angle of deviation is then $\boldsymbol{\delta = i + d}$.

The path differences are $\boldsymbol{x = c \sin i}$ and $\boldsymbol{y = c \sin d}$.

The total path difference is $\boldsymbol{c\ (\sin i + \sin d)}$

For a diffraction maximum this should be $c\,(\sin i + \sin d) = n\lambda$

$$c\left[2\sin\left(\frac{i+d}{2}\right)\cos\left(\frac{i-d}{2}\right)\right] = n\lambda$$

We can write $\sin\left(\frac{\delta}{2}\right) = \dfrac{n\lambda}{2c\cos\left(\frac{i-d}{2}\right)}$

For minimum deviation, i.e. for δ to be minimum, $\cos\left(\frac{i-d}{2}\right)$ has to be equal to one.

So for minimum deviation i=d. $\sin\left(\frac{\delta_{min}}{2}\right) = \frac{n\lambda}{2c}$

For first order diffraction n =1 $2c\,\mathrm{Sin}\left(\frac{\delta_{min}}{2}\right) = \lambda$

Part I. Adjustment of the Spectrometer

1. Focusing the telescope: Focus the telescope for the parallel rays from the distant object by sliding the eyepiece looking through telescope in and out, until a sharp image of the object is seen.

2. Leveling the collimator: Place the spirit level on the collimator tube with its axis parallel to the axis of the tube. If the position of the bubble is found to be displaced from its central position, turn the leveling screws provided with the collimator tube in the same direction to bring the bubble back to its central position. This makes the axis of the collimator tube horizontal.

3. Focusing the slit: Place a discharge lamp in front of the spectroscope and turn the telescope until it is in line with and pointing directly at the collimator. Looking through the telescope and adjusting the position of the focusing screw on the collimator until a sharp image of the slit is observed in the telescope. The collimator now gives parallel rays which will fall on the diffraction grating.

Applications

1. Trace elemental analysis in Pharmaceutical and Chemical industries (Testing the presence of metals in a sample)
2. Counterfeit Analysis (Atomic fingerprinting to keep phony products at bay)
3. Environmental testing (Determination of the amount of contamination from mines, evaluation of bore water samples)
4. Food and Beverage Testing (Evaluation of specific elements)
5. Biotechnology (In medicine for biological monitoring, Medical research).

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Procedure: (write in your own words)

Switch on the mercury vapour lamp. Adjust the collimeter of the spectrometer to obtain the sharp image of the slit. Introduce the diffraction grating. Rotate the telescope through some angle and obtain a diffraction spectrum. Rotate the grating table and watch the movement of the green line as a function of angle of rotation of the grating table. Minimum deviation is that angle at which green line retraces it path. Lock the grating table at minimum deviation. Move the telescope till the red line, lock the screw, use the other screw for small movement. Note the reading for the colour. Note the readings for different colours.

Observations:

1. No. of lines/m on the grating (N) =

2. $Least\ count = \frac{Value of\ \ 1\ MSD}{Total\ no\ of\ divisions\ \ on\ the\ vernier\ \ scale} = \frac{0.5}{30} = 0.0166$

3. Direct reading R_o = 165.167°

Observation Table:

Colour	CSR	CVR	Total reading $R = CSR + CVD \times LC$ (degrees)	$\delta_{min} = R \sim R_o$	Wavelength $\lambda = 2c\, Sin\left(\frac{\delta_{min}}{2}\right)$ (nm)
Red	144	12	144+12×0.0166 = 144.1992	20.9678	601.89
Yellow 2	145	3	=145.0498	20.1172	577.94
Yellow 1	145	8	=145.1328	20.0342	575.58
Green	146	10	=146.166	19.001	546.10
Blue	150	0	= 150	15.167	436.70
Violet 2	151	18	=151.2988	13.866	399.43
Violet 1	151	24	=151.3984	13.7686	396.64

Calculations:

1. Find the grating constant (c) using wavelength of the green line and corresponding diffraction angle.
2. Use this value of 'c' to calculate the wavelength of other spectral lines.
3. Compare the calculated values of wavelength with standard data of spectral lines from different sources. Identify the give source.

$\lambda = 2c \sin\left(\frac{\delta_{min}}{2}\right)$

$10^{-9} \times 546 = 2c \sin \frac{19}{2}$

$c = \frac{273 \times 10^{-9}}{0.1650} = 1654.54 \times 10^{-9}\ m$

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Results and conclusions:

The value of the given grating constant is $1654.54 \times 10^{-9}\ m$

The given source of light is found to be mercury light

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