



Chemical and Biological Sensors

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Detection Goals



Chemical Agents

Detection Goals in Air (mg/m³)

GB (Sarin)	0.05
GD (Soman)	0.05
VX	0.002
HD (a Mustard Gas)	5.0
L (Lewisite)	5.0

Biological Agents

Detection Goals

T-2 Toxin	2.0 mg/m ³
SEB (Staphylococcus Enterotoxian B)	0.01 mg/m ³
Botulinum Toxin	700ng/m ³ → LD ₅₀ =10ng/kg
Yersinia Pestis	6 x 10 ⁴ organisms/m ³ = 60 org./liter
Coxiella Burnetii (bacterium)	6 x 10 ⁴ organisms/m ³ = 60 org./liter
Rift Valley Fever Virus	1 x 10 ⁴ organisms/m ³ = 10 org./liter
Bacillus Anthracis(bacterium)	1 x 10 ⁴ organisms/m ³ = 10 org./liter

Typical soldier breathes 1000 liters(m³)/hour, therefore soldier has ~1hour with 10⁴ organisms/m³



Detection cont.



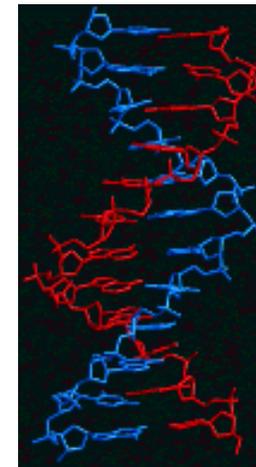
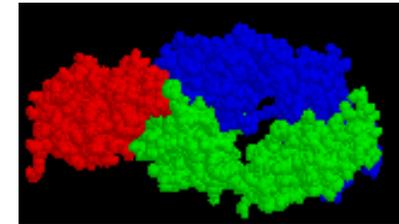
- 10^4 virus/m³ ~ 1pg/ m³
- Best Chemical Agent Monitor ~ 10μg/m³, Improvement of 10⁷ by weight
- Background spores in air: 10⁵-10⁷ spores/ m³
- Dust in air (protein and endotoxin) ~ 0.1-10 mg/m³
- Typical particles < 10 μm diameter in air: 100 μg/ m³, EPA Standard:150 μg/ m³,(24 hr av.)
- EPA Standard < 2.5 μm diameter in air: 65 μg/ m³, (24 hr av.), kitchen fumes and second hand smoke exceed this
- Pollen ~20-30 μm diameter
- Density of most viruses : 1.18-1.57 gm/ml
- Virions → $r_v \sim 20$ nm; Bacterium → $r \sim 10^3$ $r_v \sim 20$ μm ; Bacillus Subtilis var. Niger (BG) spores ~ 1.5 μm



Bioreceptor Recognition Elements



- Antibody-Antigen method
 - Specific, bind strongly, sensitive
 - Short shelf life, one time use
- DNA/RNA hybridization method
 - More specific (~20 base pairs)
 - Can be reused
 - Slow ~20 minutes
- There are many other method including enzymes and receptors





Immobilization of Bio component



- Adsorption (1 day)
 - simple, weak bond
- Microencapsulation (1 week)
 - held behind a membrane--early method
- Entrapment (3-4 weeks)
 - biomaterial is polymerized to a gel
- Cross-linking
 - bonded to a gel
- Covalent bonding (4-14 months)
 - bonded to a functional group



Transducers



- Electrochemistry (enzymes)
 - 3 Processes: potentiometry, voltametry, conductimetry
- Optical
 - UV/VIS Absorption (measure pH)
 - **Fluorescence**/luminescence (labels and intrinsic)--dyes, amino acids, NADH
 - Internal reflectance spectroscopy--**fiber optic probes**, SPM
 - Laser light scattering methods
 - RAMAN, SERS, RESONANCE RAMAN, QELS, particle sizing
- Other
 - Piezoelectric crystals (SAW, QCM), sizing, microscopy



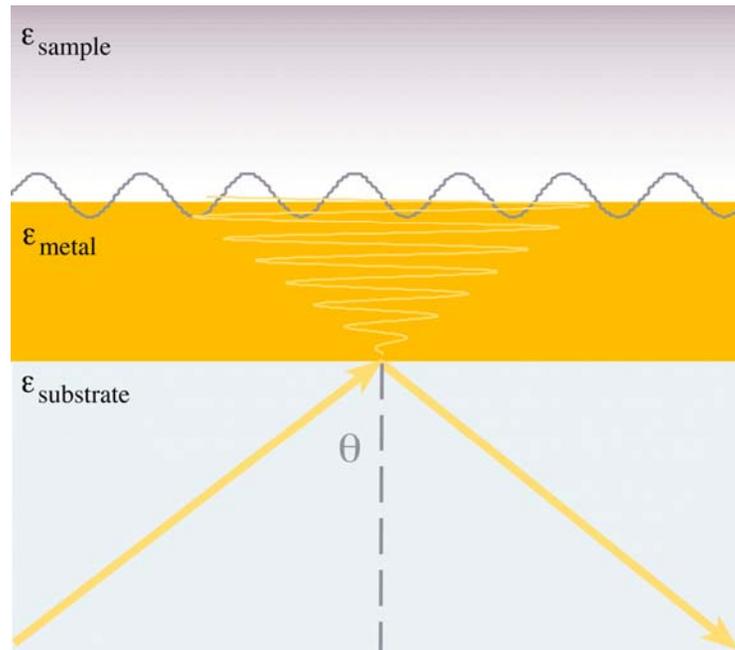
Optical Methods



- Fluorescence is the most common method
- Fiber Optic probes utilizing either antibodies or DNA hybridization are promising
- Cross sections:
 - Fluorescence: 10^{-25}
 - Raman: 10^{-31}
 - Resonance Raman: 10^{-25}
 - SERS: 4 to 14 orders of magnitude enhancement
- Fast, sensitive, small and compact
- Definite need for 280-nm (2-5 mw)

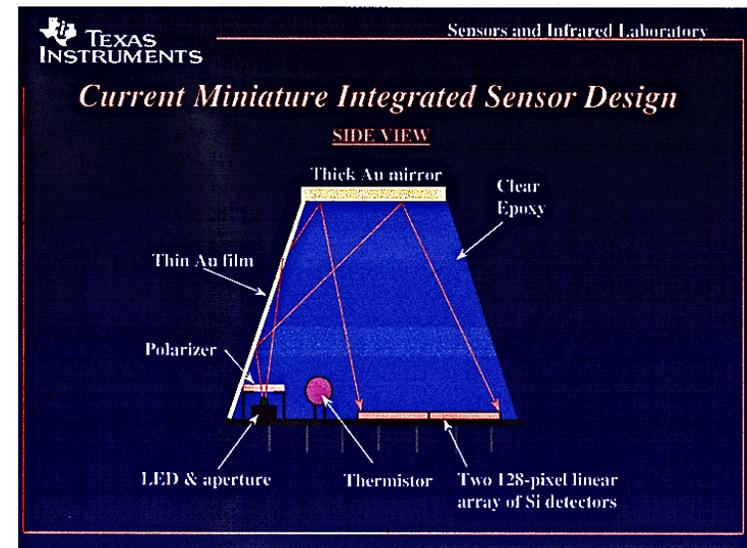


Surface Plasmon Resonance



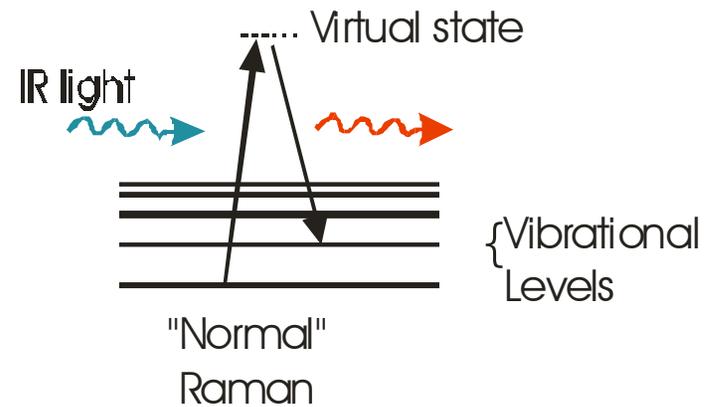
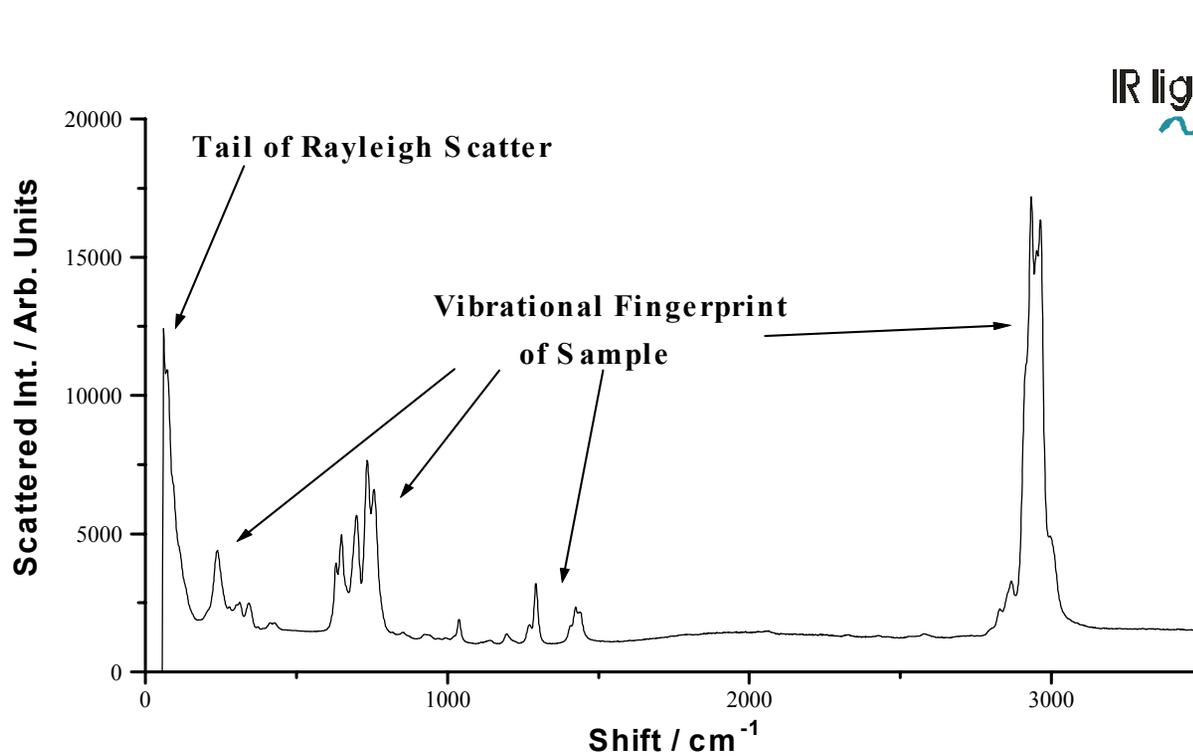
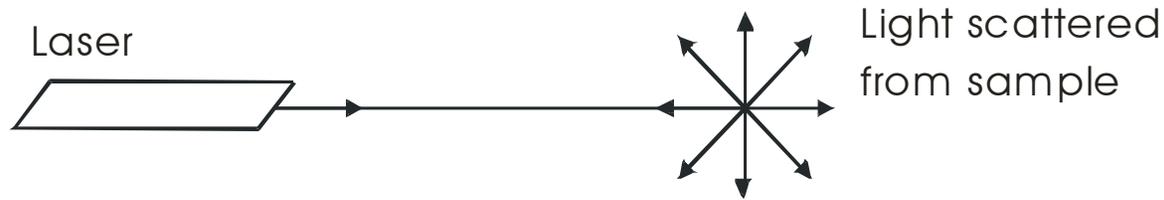
- Evanescent wave device, $\sim 250\text{nm}$
- Specificity is sometimes obtained with chem/bio-receptors

- SPR is sensitive to refractive index
- Both chem and bio applications





The Raman technique





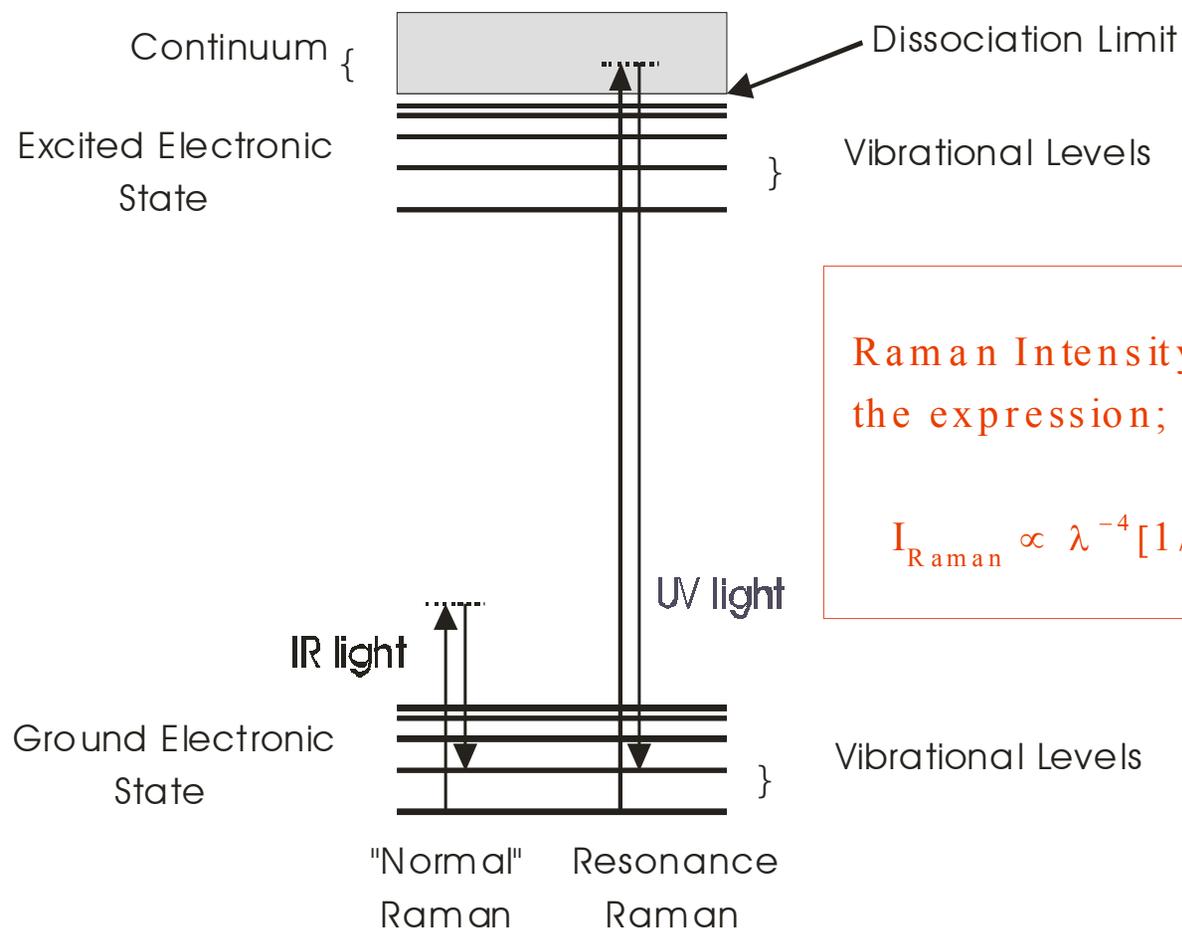
ENHANCED RAMAN SPECTROSCOPY



- Raman effect is intrinsically weak (10^8 times lower than the Rayleigh scatter)
- Resonance Raman Spectroscopy (RRS)
 - tune the laser into an absorption band signal increases of up to $\times 10^6$ can be achieved over “normal” Raman scattering.
 - Major drawback - Fluorescence: overcome by suitable selection of laser wavelength and by the use of time gated detection.
- Surface Enhanced Raman (SERS)
 - Sample adsorbed onto prepared surfaces yield increased scattering signals of up to $\times 10^6$.
 - Major drawback - Specially prepared surfaces are needed.



Resonance Raman Spectroscopy

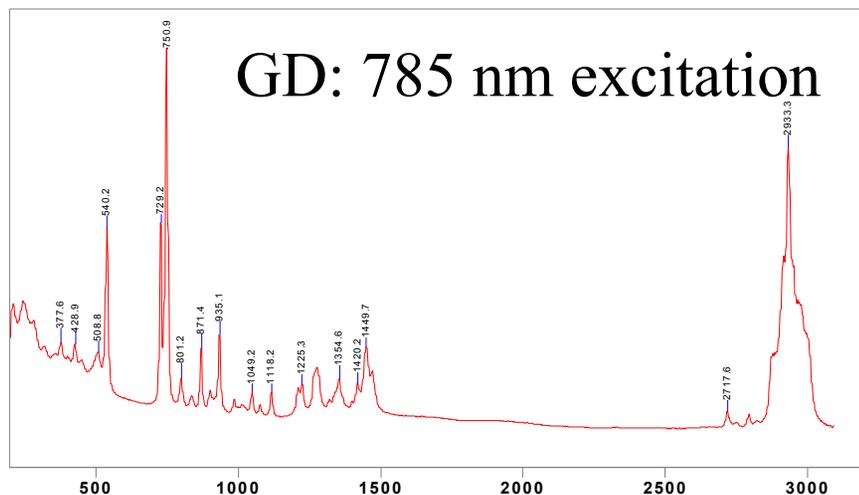


Raman Intensity is governed by the expression;

$$I_{\text{Raman}} \propto \lambda^{-4} [1/(\omega_{\text{state}} - \omega_{\text{laser}})]^2$$

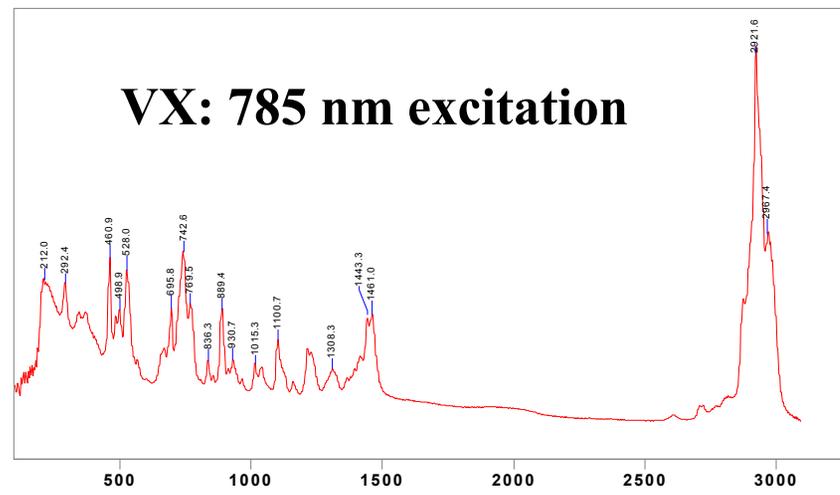


Raman Spectra of Chemical Agents



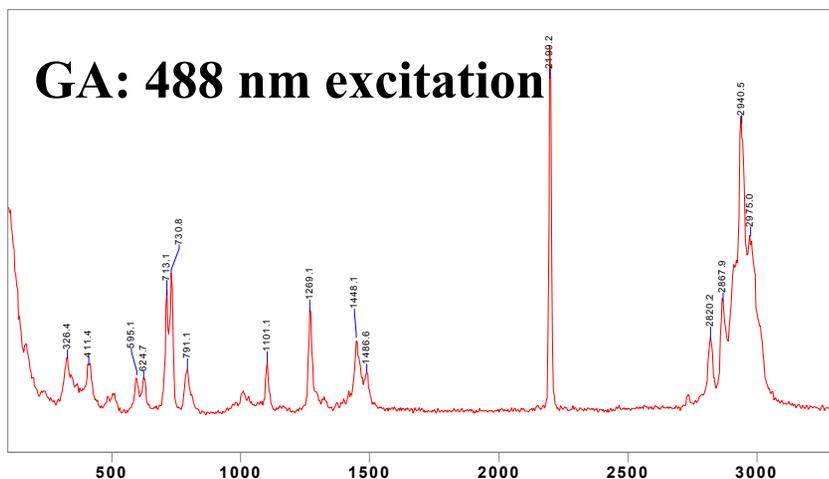
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Edgewood CB Center
US Army SBCCOM

Raman Shift (cm-1)



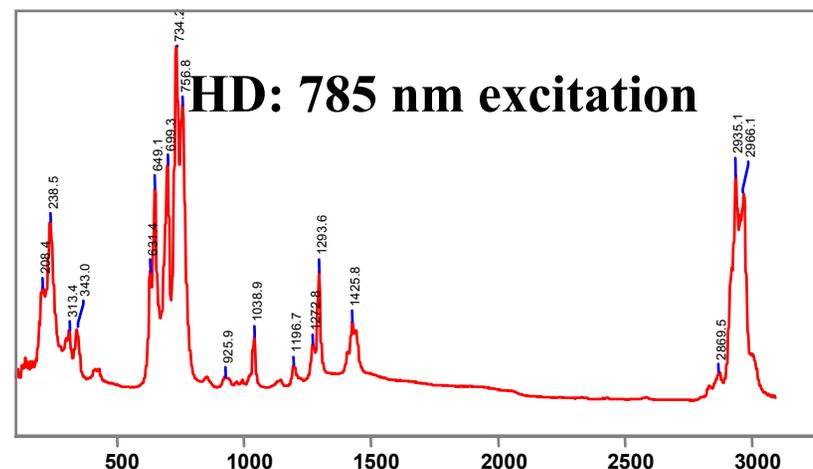
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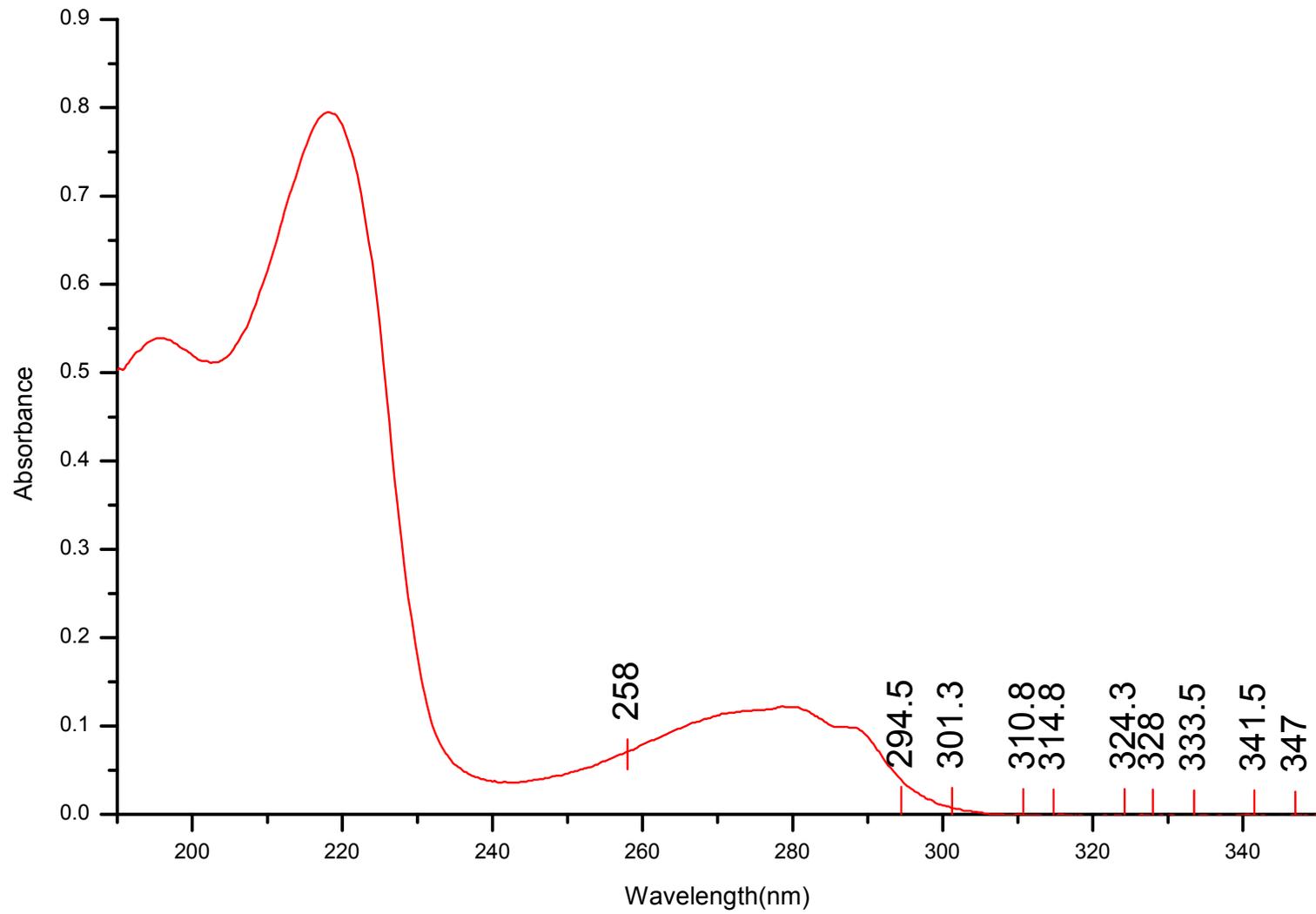


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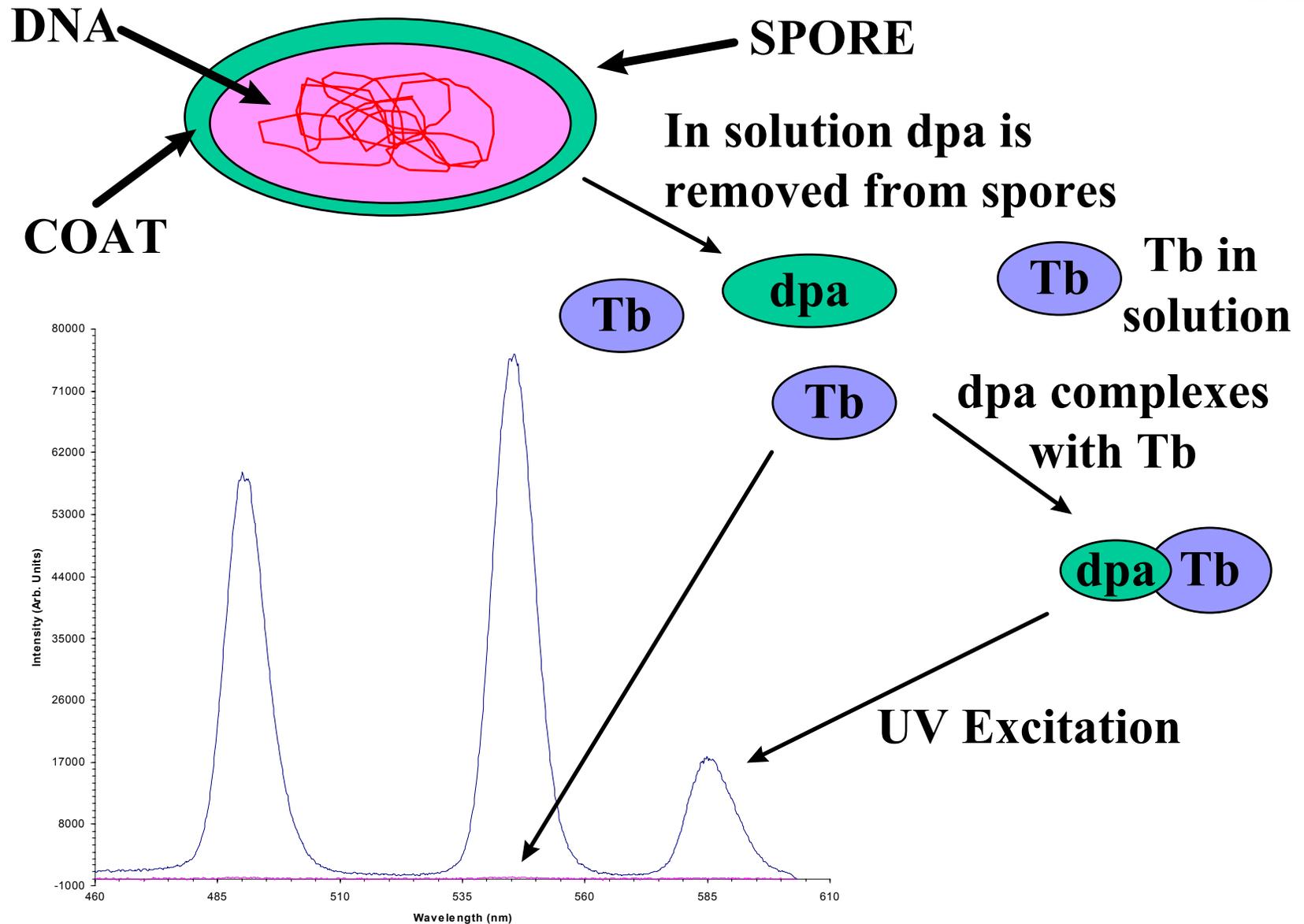


Ground state absorption spectrum of tryptophan (2×10^{-5} M) in aqueous solution



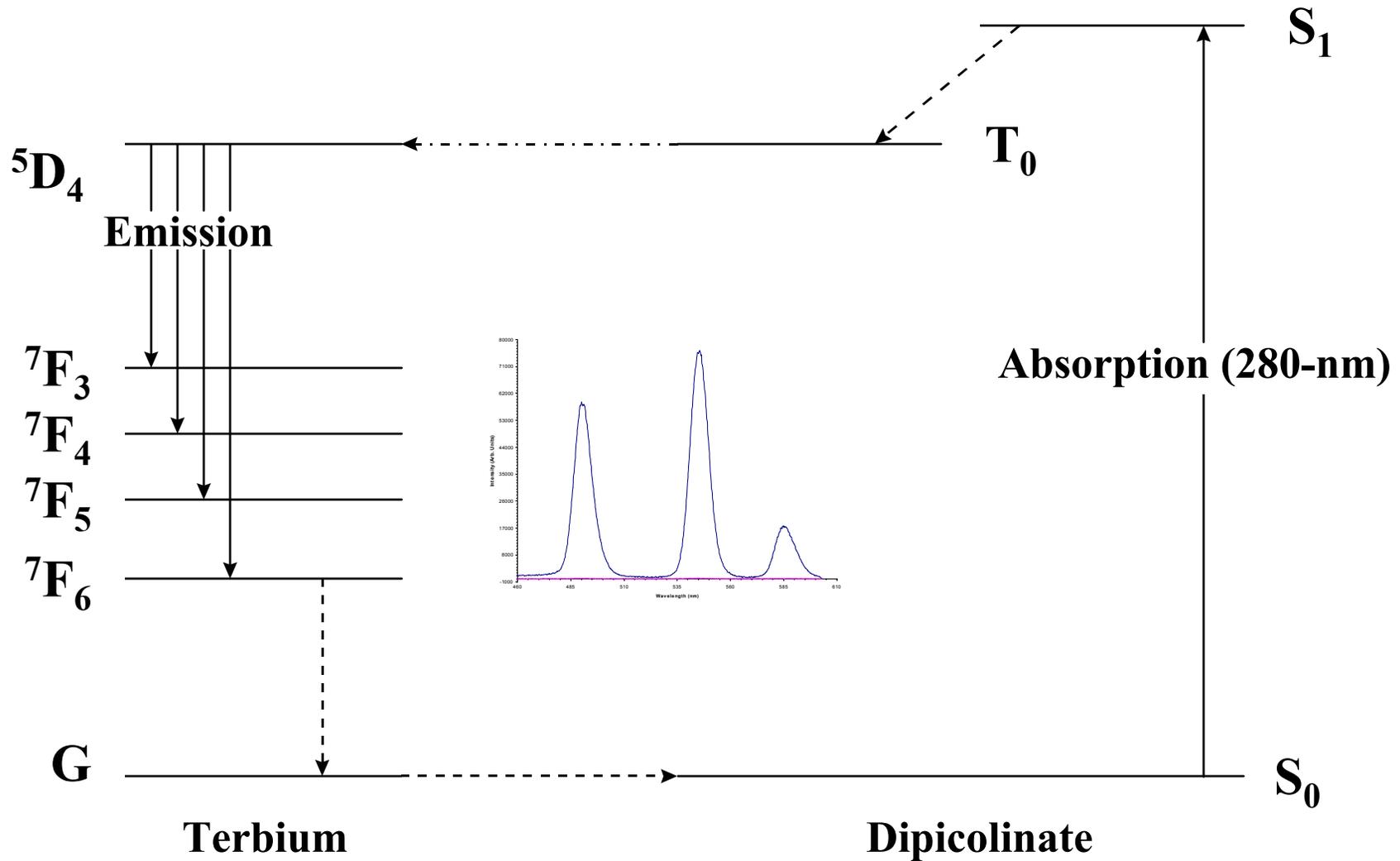


Endospore Detection Method: Tb + dpa = luminescence



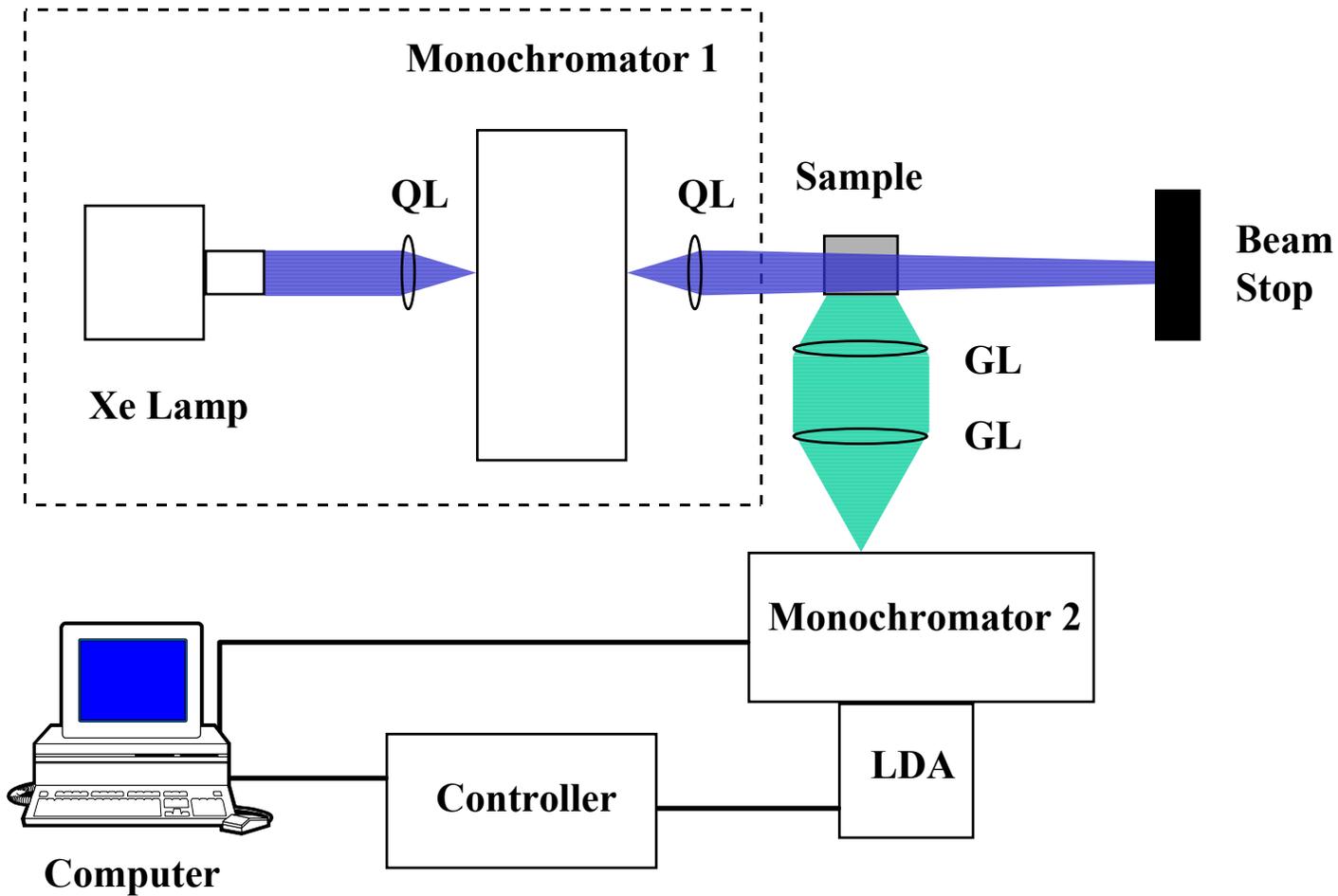


Photoluminescence of the Tb dpa Complex



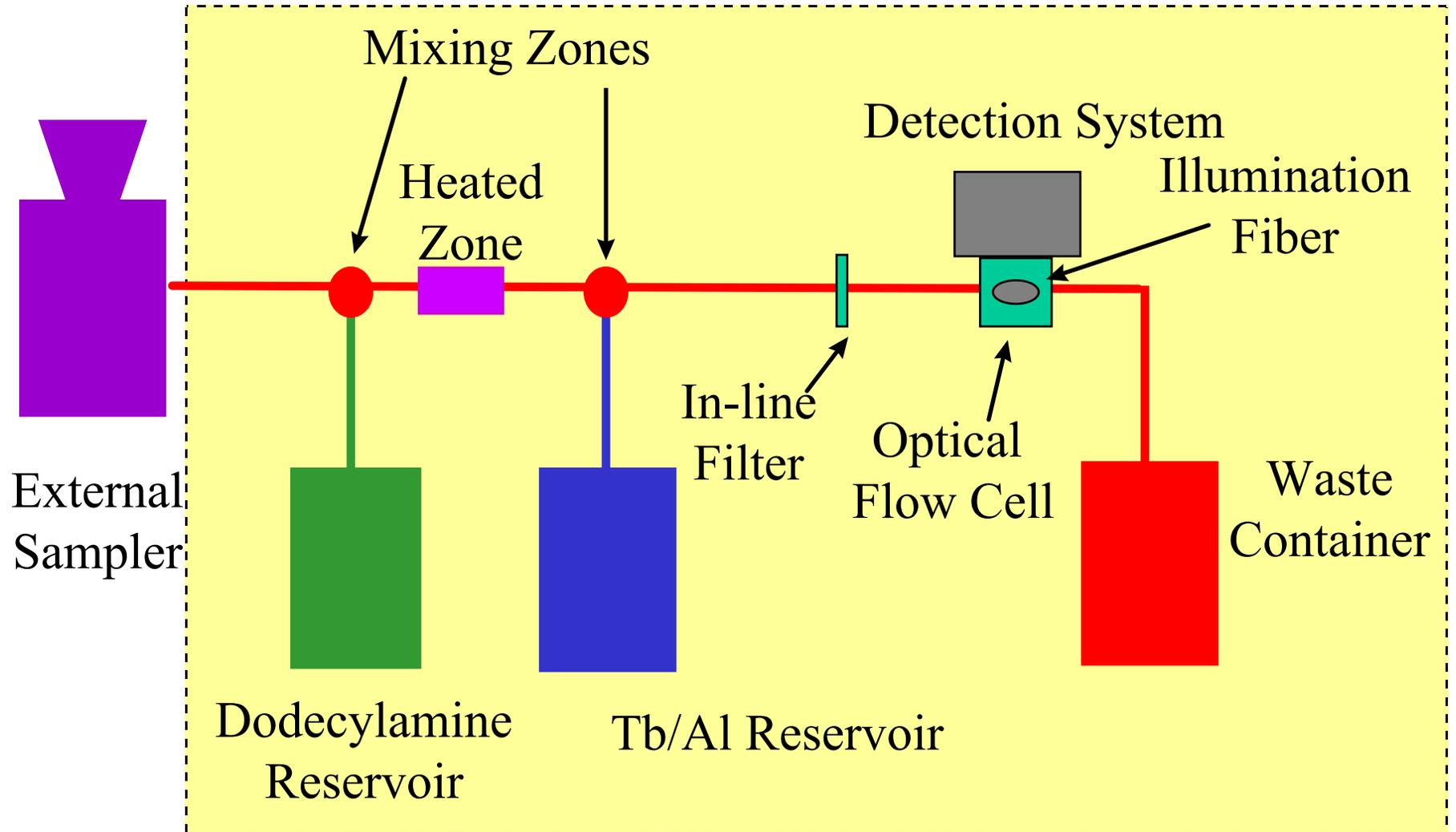


Experimental Apparatus





Notional System





Summary

(Optical methods)



- Instrumentation
 - Size, weight, power, cost, time, *in-situ*
- Resonant Raman--**very short** wavelength (200-250 nm), needs tunability, must block Rayleigh line, can be made small, specific
- Surface enhanced Raman--visible excitation
- Dipicolinate Acid absorbs at **280-nm**, spores only
- Particle counter/fluorescence can use **280-nm** UV
- Tryptophan absorbs at **280-nm**
- Networked sensors are desired, with collector, GPS