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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
34100 TRIESTE (ITALY) - P.O.B. 586 - MIRAMARE - STRADA COSTIERA 11 - TELEPHONE: 2240-1
CABLE: CENTRATOM - TELEX 460392 - I

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WINTER COLLEGE ON

ATOMIC AND MOLECULAR PHYSICS

(9 March - 3 April 1987)

BASIC SPECTROSCOPIC INSTRUMENTATION

K.S. LOW

University of Malaya
Kuala Lumpur
Malaysia

WINTER COLLEGE ON ATOMIC AND MOLECULAR PHYSICS

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS, TRIESTE, ITALY.

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BASIC SPECTROSCOPIC INSTRUMENTATION

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LECTURE 1 : REVIEW OF LASERS AND LIGHT SOURCES

1.1. Introduction

Before initiating a new project project on spectroscopy, one should evaluate the total requirement of the experiment. One should consider the cost of each piece of equipment and if some of these are not available and cannot be purchased, one should investigate if alternatives can be improvised. These 4 lectures attempt to cover the basic instrumentation that are needed for performing experiments on diagnostic atomic and molecular spectroscopy. These will include lasers/light sources, spectral filters, photodetectors, signal acquisition and processing system. Emphasis will be made on instruments that can be readily constructed. The interfacing of these devices to an inexpensive microcomputer for on-line data processing will also be discussed.

1.2. Basic Lay-out of a Spectroscopy Experiment

In Fig. 1, the general lay-out of a spectroscopy experiment is shown in block diagrams. One has here consider the microcomputer as the heart of the experiment, simply because it is now affordable and yet very versatile and powerful in its applications. On the other hand, it should not prevent anyone from doing a spectroscopy experiment in the absence of one, and particularly in the case of prototyping and initial investigations. Starting from the laser/light source, the experiment is carried out via the interaction chamber between light and matter, followed by the spectral filters, photodetectors, amplifiers, signal acquisition and averaging, data storage and finally, data analyses and presentation and computation of results. Each component in the experimental set-up will be discussed in turn, finally ending in a discussion on the usage of the microcomputer as the master controller of the experiment.

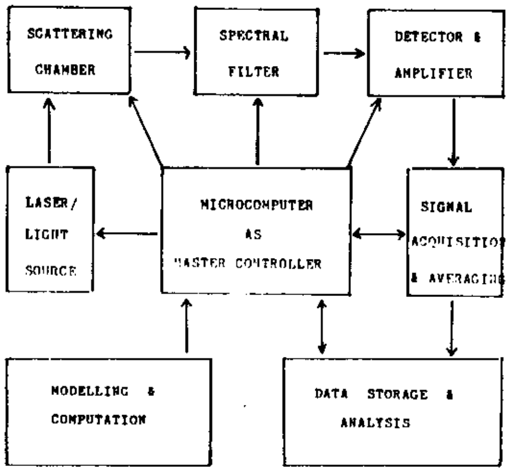


Fig. 1. Schematic Lay-out of a Microcomputer Controlled Laser Based Spectroscopic Experiment

1.3. Incoherent Light Sources

If incoherent light sources like discharge lamps and incandescent lamps are sufficient to carry out the experiment, costs in the experiment could be considerably reduced. This could vary from less than U.S.$100 for a 1 kW tungsten halogen lamp to more than a thousand for higher power xenon lamps. However, the main consideration is in whether the power output is sufficient for the experiment to be carried out. A comparison of different types of lamp sources is shown in Fig. 2. The power is typically in the range of 1 μW/cm2/nm for a 1 kW input electrical energy. This power density is at least a million times less than most laser sources.

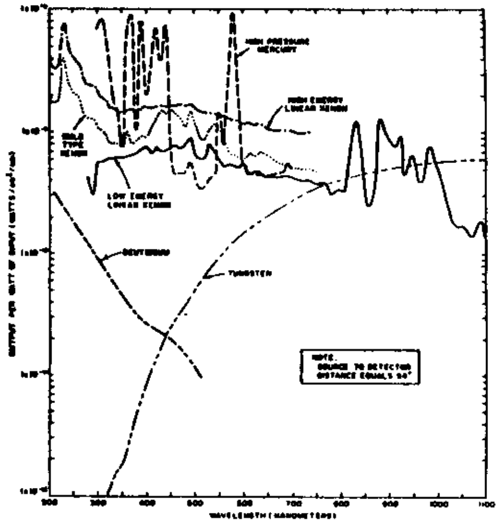


Fig. 2. Xenon flashlamp spectrum versus other commonly used optical sources.

On the other hand, xenon lamps and tungsten halogen lamps are still useful in many routine scientific and laboratory applications.
e.g. in absorption spectrometers and in spectrofluorometers for routine chemical analyses and diagnoses.

Other incoherent light sources include solar radiation and in particular in remote sensing techniques from the satellites. There is also considerable works on IR spectroscopy using Nernst glowers and arc sources for molecular spectroscopy.

Also, the following topics will be discussed subsequently

1. Prof. Platt will be discussing later a novel method of performing differential optical absorption spectrometry using ordinary search lights for the long path monitoring of ambient trace molecules to very high resolution, (& also the seminar of C.K. Lee et. al)

2. Prof. Svanberg will be comparing the fluorescence of Hpd (for cancer diagnosis) using lasers as compared to using high power xenon or mercury lamps.

3. Inexpensive tungsten halogen lamps (projector lamps) can also be used for cancer therapy. (Seminar of M. Olivo et. al.)

4. In the topic of hydrospheric and atmospheric diagnostics, Professors Svanberg and Gjessing will be discussing various remote sensing schemes, using solar radiation, IR and also microwaves.

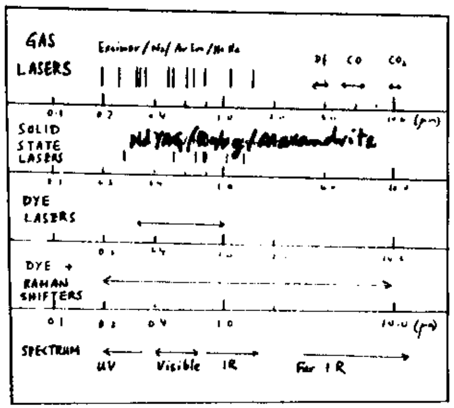
1.4. Laser Sources

Lasers, as discussed is many times more intense than ordinary lamp sources. Their costs are also more or less correspondingly increased, except in the case of the mass produced diode lasers and He-Ne lasers. The cost can range from U.S.$5,000 to more than $100,000 depending on the type and the power requirements. On the other hand, some of these lasers can be constructed rather easily. This will be discussed further in the next lecture.

Applications of lasers: need to know the types of lasers with respect to

1. wavelength and types
2. power
3. bandwidth and coherence

1. Wavelength spectrum of lasers available : Fig. 3.



Types of lasers

FIR → visible → UV

Continuous wave (CW) or pulsed

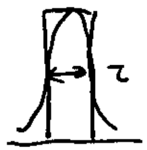
CW Lasers
- mainly gas discharge lasers
- or dye lasers pumped by gas lasers
- mW to tens of KW
- easiest to develop

Pulse lasers
- normally from capacitor discharge in gas lasers or from flashlights
- from ms to picosec & subpicoseconds – femtoseconds 10^{-15} s
- high peak power
- TEA-CO_2 and Nd-glass lasers

> 10 KJ

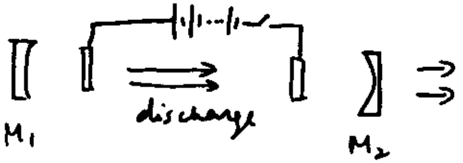
10 KJ if 1 ns pulse

then $\frac{10\ KJ}{1\ ns} \Rightarrow 10^{13}$ W peak



Gas lasers

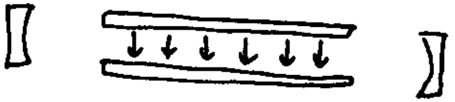
- high voltage gas discharge pump
- ionisation & excitation
- longitudinal discharge or transverse discharge



⇒ output along axis of discharge
- Longitudinal

since output power ∝ volume of gaseous molecules involved
- increase length of active discharge or increase the pressure of gases
- require too high voltage to initiate and maintain discharge

∴ Use transverse electric discharge



⇒ output

Lower operating voltage & can increase operating pressure
in fact, even to atmospheric pressure

TEA — Transverse electric atmospheric lasers

most commonly used gas lasers

① He-Ne — CW — 632.8 nm, Neon red light, low power 1 mW → 50 mW
useful for teaching laboratories, alignment & even for acupuncture & other medical applications

② Argon ion — CW — < 20W — 514.5, 488 nm green blue
useful for pumping dyes
spectroscopy
cancer research
opthalmology

③ CO_2 laser 10.6 μm - vibrational
- CW to tens of KW
  - longitudinal discharge
- pulse to tens of KJ (for fusion program)
  - transverse discharge

for material processing, cutting welding, heat treatment, precision drilling & shaping

④ N_2 laser — UV 337.1 nm
short pulse (~5 ns) high peak power, transverse electric
useful for pumping dye & for fluorescence work

(5) Excimer laser : UV TEA design

rare gas halide = fast high voltage discharge

eg Xe + Cl $\xrightarrow{\text{discharge}}$ XeCl*

↑ noble gas, no bound molecule

↑ excited states form a dimer 'excimer'

XeCl	308 nm	a few Joule/pulse
XeF	351	
ArF	193	→ 1000 Hz
KrF	248	

single 10 KJ KrF pulse for laser fusion program

(6) Chemical laser

- does not refer to the medium but the means of generating population inversion

eg H + Cl_2 → HCl + Cl + energy

a few KJ , HF chemical laser

Solid state lasers

(1) Ruby laser Cr^{3+} ion in Al_2O_3

red 694.3 nm

pulse - Q switch to give giant pulse

(2) Nd - YAG

Nd^{3+} in Yttrium Aluminium garnate rod

· Nd - glass

high peak power 1.06 μm

tens of KJ for fusion research

Very compact for laser range finder

Very versatile : pump dye

material processing etc

(3) Semiconductor

LED → laser diodes IR

optical communication

Liquid lasers

complex dye molecules

tunable from UV to IR

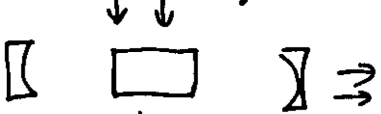
Exciting light

← fluorescence that can be made to lase

Pumping light sources

- flashlamp pumped
- other laser pumped
  - eg. Argon ion
  - N_2
  - Nd-YAG
  - Excimer

External light



dye cell

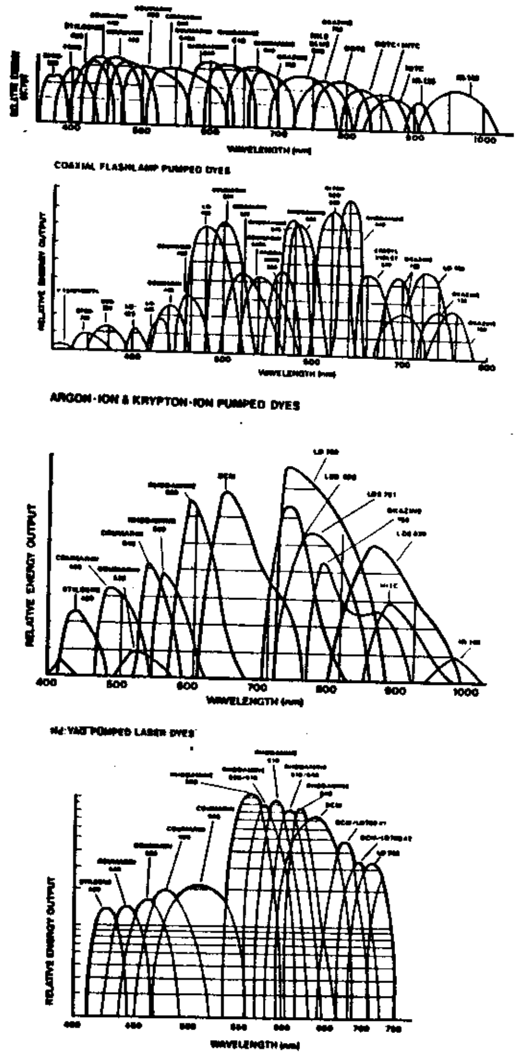


Fig. 4. Spectrum of dye laser output with different pump sources.

Wavelength selection

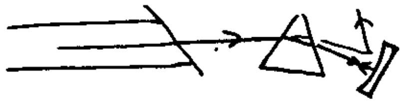
Except for dye laser output, most laser lines have specific wavelengths.

– from vacuum UV to Far IR

Some lasers have a few lines
– need to select

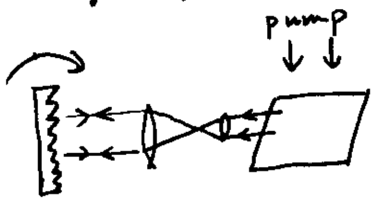
For dye lasers, tune output

① simplest, use prism tuning as in Argon ion laser



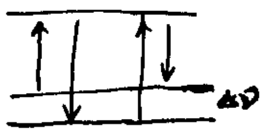
② Use intra cavity etalon for dye lasers, narrow gap

③ Use grating in different mounting arrangements



as in N_2 laser pumped dye laser

④ Use Raman shifters
$\Delta\nu$ in Hydrogen cell



Raman Shifters : Pressurize Hydrogen gas cell
Stokes to longer wavelengths
Anti-Stokes to shorter wavelength
– cover from UV to far IR

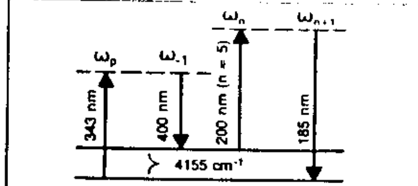


Fig. 1: Generation of 1st Stokes at 400 nm of an excimer-pumped dye laser operating at 343 nm (PTP) with subsequent generation of higher-order Anti-Stokes.

* Excimer-pumped dye lasers can be operated most efficiently in the range from 330 nm to 870 nm. Nd:Yag-pumped dye lasers are operated most efficiently in the range from 540 nm to 820 nm

** The dye laser output power should exceed 20 mJ in order to obtain reliable Raman-operation.

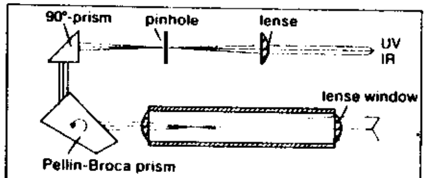


Fig. 2: Design of RS 75 Raman-cell. Line selection without beam displacement by rotating the Pellin-Broca prism. CaF_2-optics available for λ < 190 nm (RS 75 VUV)

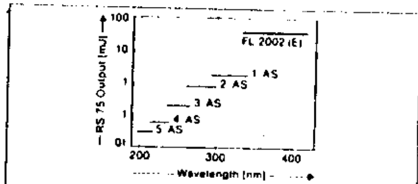


Fig. 3: UV-output of RS 75 (Anti-Stokes) when pumped with UV-dye laser excimer-driven (EMG 200 series). The conversion efficiency can be further increased by cooling the Raman-medium and by use of special coatings for the optics involved

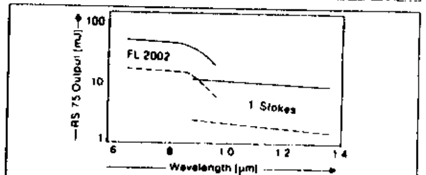


Fig. 4: IR-output of RS 75 (Stokes) when pumped with IR-dye laser. When using the powerful EMG 200 series/FL 2002 dye laser systems tuned to 950 nm, the corresponding Raman-wavelength can even reach 1.57 µm. Dye laser optimized for minimum beam divergence
(—— EMG 200 pumped, ---- EMG 100 pumped)

Useful reference to get started with lasers & spectroscopy :
'Laser Focus Buyer's Guide' for addresses of suppliers of optical components, lasers, light sources etc.
Ask for Products catalogs from some of these suppliers