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Modified Mercury Lamp as an Ultraviolet Sterilizer

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Abstract
A high-pressure mercury lamp for street lighting with the outer balloon removed can be used as an artificial source of UV radiation. The paper shows the method of obtaining UV sources from ordinary mercury lamps the method of connection and the principle of operation. The spectrum of the emitted wavelengths of the mercury lamp with the outer balloon removed is shown, as well as checking the presence of UV radiation with an electroscope and possible application for environmental sterilization in medicine and biology.

Keywords: Mercury lamp, ultraviolet radiation, sterilization.

1. Introduction

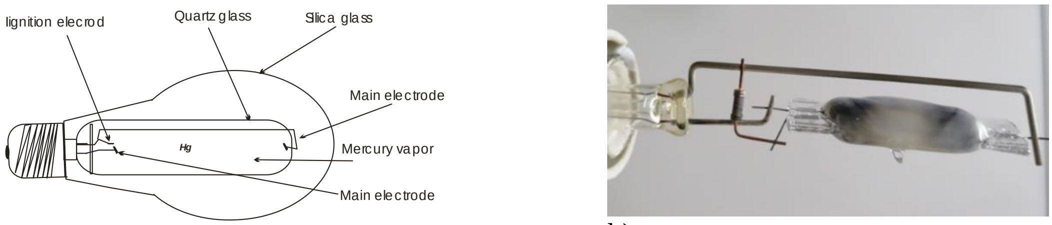
UV radiation is electromagnetic (EM) radiation with a wavelength in the range of 100-400 nm. Radiation with wavelengths within this range is emitted by high-temperature surfaces, such as the sun and hot metals, as a continuous spectrum. Other sources of UV radiation are electric discharges through gases and vapors at high and low pressures, with spectra in the form of bands and lines.
According to the CEE (Commission Internationale de l'Eclairage) definition, UV radiation is divided into three areas: UV-C region (λ = 100-280 nm), UV-B region (λ = 280-315 nm) and UV-A region (λ = 315-400 nm)[1].
UV-A radiation consists of about 98% of the total solar UV radiation that reaches the Earth's surface. It stimulates the synthesis of vitamin D from its provitamin, as well as fluorescence in certain materials. UV-B radiation has a destructive effect on biological organisms, can lead to various damages to the skin and eye tissue, and is well absorbed in the atmosphere. UV-C radiation is completely absorbed in the ozone layer of the atmosphere-stratosphere. It has a destructive effect on DNA and bactericidal effect, and is used for air sterilization (operating rooms, infectious disease clinics) and water sterilization, using artificial sources of UV-C radiation, the so-called germicidal lamps [1].
The intention of the work is to show that a mercury lamp for street lighting with the outer balloon removed emits part of the UV radiation that belongs to the UV-C spectrum, making it usable as an alternative to germicidal lamps for sterilizing smaller rooms. In order to prove that the lamp emits radiation in the UV-C region of the spectrum during operation, a monochromator was used. Considering that such a device is not available to everyone, an alternative way of detecting UV radiation based on the photo effect is described.

2. A high-pressure mercury lamp with the outer balloon removed as an artificial source of UV radiation.

A standard mercury lamp consists of an outer glass balloon with a luminophore and an inner quartz glass bulb containing a small amount of mercury in argon as it is depicted in Fig. 1a. The primary type of electrical discharge in a high-pressure mercury lamp is an electric arc [2].

2.1. The operation principle of the mercury lamp

Three electrodes are inserted into the quartz bulb, two main and one for ignition (Fig. 1a). They are placed so that the distance between the main electrode and the ignition electrode is small, compared to the distance between the main electrodes. When the voltage is applied, a discharge occurs between the main and the ignition electrode, because the electric field is strong enough due to the small radius of the curvature of the tip of the ignition electrode (spike), which leads to an electrical breakdown in the gas. As a result, visible blue and violet radiation can be seen containing UV radiation. The maximum current through the bulb is determined by the ballast, which must be connected in series with the bulb [2]. If the outer balloon is not removed, the UV radiation is absorbed by the luminophore located on its inner walls and emitted as white light. Therefore, it is necessary to remove the outer balloon as shown in Fig. 1b.



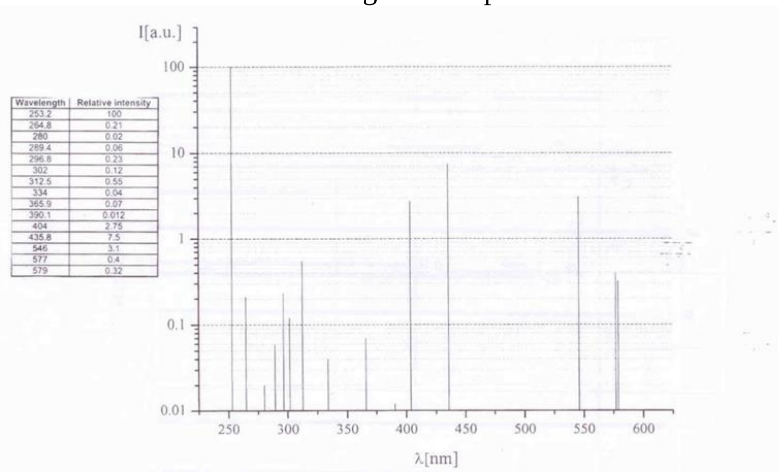
a) b)

Figure 1: a) schematic representation of mercury lamp; b) real mercury lamp without outer balloon

2.2. Detection of UV radiation

A Karl Zeiss SPM2 monochromator with a photomultiplier tube and an AMINCO amplifier was used to prove the presence of UV radiation. By recording the spectrum of the street mercury lamp, with the outer balloon removed, the presence of wavelengths in the interval from 240 nm to 410 nm was detected as it is shown in Fig. 2.

Based on the measured results, given in Fig. 2, it is clear that the mercury streetlamp with the outer balloon removed emits radiation in the UV-C range of the spectrum.



Wavelength	Relative intensity
253.2	100
264.8	0.21
280	0.02
289.4	0.06
296.8	0.23
302	0.12
312.5	0.55
334	0.04
365.9	0.07
390.1	0.012
404	2.75
435.8	7.5
546	3.1
577	0.4
579	0.32

Figure 2: The spectrum of the street mercury lamp with the outer balloon removed

2.3. Detection of UV radiation by the photoelectric effect

The phenomenon that some metals emit electrons from their surface under the influence of light is called the photoelectric effect [3]. An electroscope was used to prove the presence of UV radiation. In this way, students were enabled to detect UV radiation using a mercury lamp and an electroscope, and at the same time they can become familiar with the photoelectric effect (Fig. 3). It should be emphasized that the demonstration of the photoelectric effect is not the primary goal, but it is used for the detection of UV-C radiation when a monochromator is not available.

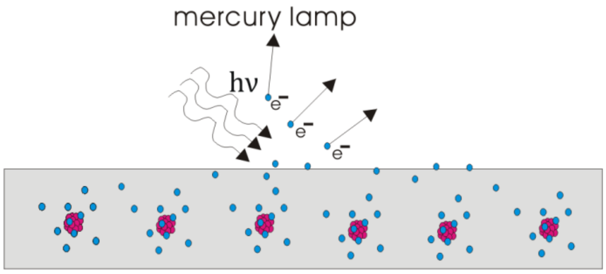


Figure 3: The photoelectric effect

The demonstration of the photoelectric effect is performed by changing metal plates of different materials (Al, Cu, Zn, Ni) attached to the contact of the electroscope located at the top. With the negatively charged electroscope, shown in Fig. 4a, a UV lamp is placed in the immediate vicinity of the metal plate, during which the discharge of the electroscope can be seen as depicted in Fig. 4b. The UV radiation energy of the described lamp is sufficient to cause the photoelectric effect.

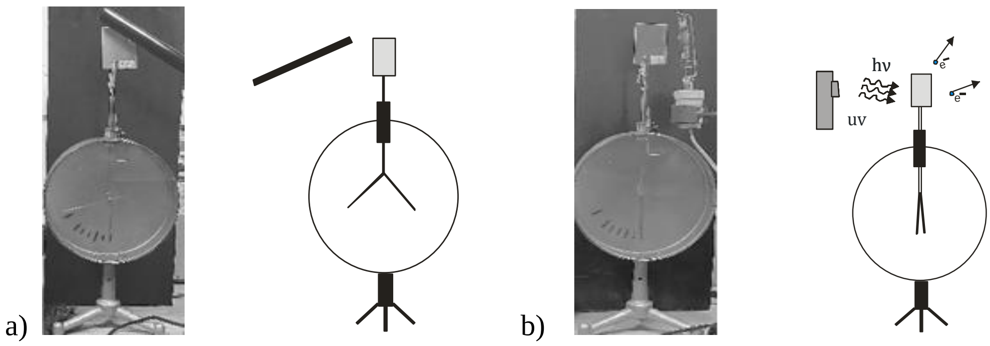


Figure 4: a) charged electroscope; b) discharged electroscope

The minimum energy that an electron needs to receive to leave the surface of the plate is equal to the work function of the electron for a given metal. Using Einstein's equation for the photoelectric effect:

$$h\nu = A_i + E_k \tag{1}$$

the maximum wavelength required to establish the photoelectric effect can be calculated as:

$$\lambda_{max} = \frac{hc}{A_i} \tag{2}$$

Using different metal plates and Einstein's equation for the photoelectric effect [3] and the values of work function for the given metals [4], the minimum frequency for the appearance of the photoelectric effect as shown by the discharged electroscope was calculated. The calculated values for the wavelengths λ_{max} were: 248.24 nm for Ni, 275 nm for Cu, 285 nm for Zn and 309 nm for Al, which confirms the presence of UV-C radiation.

2.4. Application of the mercury lamp with the outer balloon removed

Based on the measured and calculated values of the wavelengths of UV radiation, it is clear that the lamp with the outer balloon removed can be used as a sterilizer. When working with this kind of lamp, one should be very careful and the usage of protective glasses for UV radiation is necessary. Shortly after ignition, a characteristic smell is felt in the room, which indicates the presence of ozone (see Fig.5) created under the effect of UV radiation with shorter wavelengths of 100-240 nm. Therefore, during the operation of the lamp while sterilizing the room, it is not recommended to stay in the room. After finishing the treatment (exposure of the room to UV-C radiation), the lamp should be turned off and then the room should be ventilated [1].

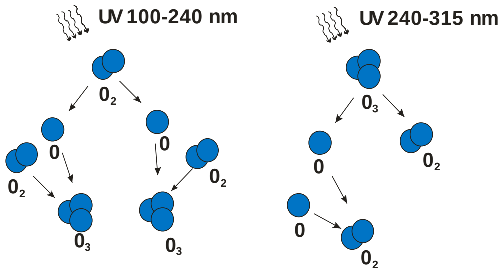


Figure 5: The process of creation and decay of ozone in the atmosphere under the influence of UV emission.

UV radiation has a germicidal effect on microorganisms too. Electromagnetic waves with the smallest wavelengths have the highest energy, and therefore, as expected, the highest germicidal effect. It has been shown that the most effective rays have wavelengths in the range of 228-290 nm. The reason for this is that rays of these wavelengths are absorbed by deoxyribonucleic acids (DNA) and ribonucleic acids (RNA) in the cell's core, damaging them and thus preventing their reproduction [1].

3. Conclusion

By removing the outer bulb of an ordinary mercury lamp for street lighting, a source of UV radiation is obtained. The UV spectrum of this lamp contains a UV-C part which was detected using a monochromator. A description of another way of detecting UV-C radiation, based on the photoelectric effect using an electroscope – an available device in all primary and secondary schools, was described. The proven existence of UV-C radiation in this lamp's spectra, gives an opportunity for its use for sterilization of smaller rooms with mandatory observance of protective measures.

References

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