Review

Fluorescent and Phosphorescent Nitrogen-Containing Heterocycles and Crown Ethers: Biological and Pharmaceutical Applications

Faiz Ullah 1,†, Sami Ullah 2, Muhammad Farhan Ali Khan 3, Muhammad Mustaqeem 4, Rizwan Nasir Paracha 5, Muhammad Fayyaz ur Rehman 4, Fariha Kanwal 6, Syed Shams ul Hassan 7,8,† and Simona Bungau 9,†

1 Department of Chemistry, Quaid I Azam University, Islamabad 45320, Pakistan
2 Department of Zoology, Government College University, Faisalabad 38000, Pakistan
3 Faculty of Pharmacy, Capital University of Science and Technology, Islamabad Expressway, Islamabad 44000, Pakistan
4 Institute of Chemistry, University of Sargodha, Sargodha 40100, Pakistan
5 Department of Chemistry, Sub Campus, University of Sargodha, Bhakkar 30000, Pakistan
6 School of Biomedical Engineering, Shanghai Jiao Tong University, 1545 Huanshan Dong Road, Shanghai 200030, China
7 Shanghai Key Laboratory for Molecular Engineering of Chiral Drugs, School of Pharmacy, Shanghai Jiao Tong University, Shanghai 200240, China
8 Department of Natural Product Chemistry, School of Pharmacy, Shanghai Jiao Tong University, Shanghai 200240, China
9 Department of Pharmacy, Faculty of Medicine and Pharmacy, University of Oradea, 410028 Oradea, Romania

† Correspondence: faizullah@chem.qau.edu.pk (F.U.); shams1327@yahoo.com (S.S.u.H.); simonabungau@gmail.com (S.B.)

Abstract: Fluorescent molecules absorb photons of specific wavelengths and emit a longer wavelength photon within nanoseconds. Recently, fluorescent materials have been widely used in the life and material sciences. Fluorescently labelled heterocyclic compounds are useful in bioanalytical applications, including in vivo imaging, high throughput screening, diagnostics, and light-emitting diodes. These compounds have various therapeutic properties, including antifungal, antitumor, antimarial, anti-inflammatory, and analgesic activities. Different neutral fluorescent markers containing nitrogen heterocycles (quinolones, azafluoranthenes, pyrazoloquinolines, etc.) have several electrochemical, biological, and nonlinear optic applications. Photodynamic therapy (PDT), which destroys tumors and keeps normal tissues safe, works in the presence of molecular oxygen with light and a photosensitizing drugs (dye) to obtain a therapeutic effect. These compounds can potentially be effective templates for producing devices used in biological research. Blending crown compounds with fluorescent residues to create sensors has been frequently investigated. Fluorescent heterocyclic compounds (crown ether) increase metal solubility in non-aqueous fluids, broadening the application window. Fluorescent supramolecular polymers have widespread use in fluorescent materials, fluorescence probing, data storage, bio-imaging, drug administration, reproduction, biocatalysis, and cancer treatment. The employment of fluorophores, including organic chromophores and crown ethers, which have high selectivity, sensitivity, and stability constants, opens up new avenues for research. Fluorescent organic compounds are gaining importance in the biological world daily because of their diverse functionality with remarkable structural features and positive properties in the fields of medicine, pharmacy, and spectroscopy.

Keywords: fluorescence; heterocyclic compounds; antitumor; antifungal; anti-microbial

1. Introduction

Molecular luminescence approaches include phosphorescence and fluorescence. A photon is absorbed by an analyte molecule, which stimulates a species. The emission spectrum can be used for quantitative and qualitative studies [1,2]. Because of their
potential various functional applications, luminous materials have received significant attention lately [3]. They have been widely employed, including in the food, pharmaceutical, optical, and textile sectors [4,5]. Conventionally, inorganic emitting materials were commonly used; however, organic luminescent materials with brilliant emission have largely replaced them due to their wide range of uses, including emergency lighting, low cost, environmental friendliness, long-term solutions, anti-counterfeiting displays, and in food, cosmetics, polymers, bioactive molecules, and biochemistry [6,7]. Furthermore, in today’s research, the design of novel luminous hybrid organic–nonorganic materials is critical [8,9]. The combination of phosphorescent dye as a sensitizer co-doped with a fluorescence emitter has made progress in developing luminescent materials for organic light-emitting diodes (OLEDs) in recent years [10,11].

Fluorescence quenching or fluorescence enhancement is employed as an analytical technique [12,13]. The fluorescent labelling of the host molecule complex provides a useful tool for detecting the analyte’s attachment to the host molecule [14–16]. For example, protein labelling using small molecule-based fluorescent probes is used in various biological experiments and is a valuable technique for determining the expression level and localization of a protein of interest in living cells [17].

Due to particular biological activity, crown ether’s derivate and \( N \)-containing heterocyclic chemicals and their derivatives have been widely employed in agronomy and medicine [18]. Similar organic chemicals are of interest in pharmacology as effective tissue oxygenators and antidepressants, as well as in biotechnology; these compounds are employed for macromolecule binding [19–23]. \( N \)-containing heterocyclic compounds and macrocycle derivative crown ethers have remarkable photochemical, catalytic, and luminescent capabilities, indicating that they might be used to diagnose and cure various ailments. A few of their applications include photodynamic treatment and antimicrobial/antiparasitic activities against human pathogens and malarial parasites. Employment of fluorophores, including organic chromophores and crown ethers, with high selectivity, sensitivity, and stability constants while detecting tumor cells opens up new avenues for cancer research [24,25].

Macrocyclic molecules, for example, crown ether, have been used in a wide range of chemical processes, including selective metal complexing agents and photo-induced electron transfer bio-mimetic research [26–29]. In contrast to the extensive coordination chemistry, little is known about crown ether coordination compounds’ photoluminescence (PL). Crown ethers substituted with particular fluorescent dyes were the most commonly reported for PL. The use of such dye-substituted systems in sensing and analytical chemistry to detect the presence of particular metal cations was intensively investigated [30–32].

A smart fluorescent probe with a crown ether moiety might be constructed as a sensor for metal anions, ions, and other biomolecules and then used to monitor biological processes in vivo [33]. The solvent effects of a crown ether complex containing a fluorescent anthracene unit are exceptional [34].

Supramolecular chemistry, inspired by nature’s vast array of assemblies, has garnered significant attention in recent decades due to its diverse supra-structures, which consist of micelles, vesicles, and fibers, as well as its wide-ranging applications in sensors, drug delivery, luminescent materials, and bioimaging [35–38].

Fluorescence characteristics of \( N \)-containing heterocyclic compounds have recently received considerable interest. For example, fluorescent compounds known as quinolines have attracted the attention of scientists because of their use in high-tech applications [39]. Similarly, derivatives of the pyrazoloquinoline (PQ) family and quinoline are an example of fluorescent substances that may be of interest for several applications, including their use as oxidant scavengers and growth promoters [40,41]. These have also been found naturally in a wide range of foods and appear to be easily absorbed. More recently, heterocyclic azo compounds such as benzothiazole, pyrazole, and thiazole have been employed for electrochemical, biological, and nonlinear optics applications and structure–activity relationships for drug designing [SAR] [42–44]. Thiophene and thienopy-
rimidine derivatives have fluorescence features and are more efficient than other aromatic chemicals for anti-avian influenza virus (H5N1) action. Porphyrins are N-heterocyclic chemicals present in a wide variety of biological systems. Metalloporphyrins contain solely -pyrrolic substituents in biological systems and appear attached to proteins, creating supramolecular structures such as haemoglobin, myoglobin, cytochromes, catalases, and peroxidases, as well as chlorophylls and bacteriochlorophylls in reduced forms [45].

Within the constraints of this review, it is not feasible to address the fluorescence characteristics of all compounds of interest in biochemistry and medicine. However, crown ether and N-containing heterocyclic compounds that show fluorescence capabilities are chosen for this section to demonstrate their biological and pharmaceutical applications in daily life.

2. Applications of Heterocyclic Compounds

2.1. Anti-Mycobacterial Activity

Different symptoms such as respiratory issues, long-term coughs, and tuberculosis are treated by various plants in African and Asian countries. Many anti-tubercular drugs, with toxicity and side effects, are still used to treat tuberculosis. For treating M. tuberculosis, the synthesis of azo compounds was monitored and showed anti-tubercular activity. Maximum activity was shown by compounds 5-methyl-2-(5-methylbenzo[d]thiazol-2-yl)-4-(p-tolyl diazenyl)-1H-pyrazol-3(2H)-one (1a) and 5-methyl-2-(5-methylbenzo[d]thiazol-2-yl)-4-(m-tolyl diazenyl)-1H-pyrazol-3(2H)-one (1b) when compared to the compounds 4-((4-chlorophenyl)diazenyl)-5-methyl-2-(5-methylbenzo[d]thiazol-2-yl)-1H-pyrazol-3(2H)-one (1c) and 4-((4-bromophenyl)diazenyl)-5-methyl-2-(5-methylbenzo[d]-thiazol-2-yl)-1H-pyrazol-3(2H)-one (1d) shown below in Figure 1, correspondingly. A previous study shows that the presence of a side chain to an azo dye along with a phenyl group substituent and a significantly enhanced electron-donating group ultimately decreased the growth of bacteria [5].

![Figure 1](image)

**Figure 1.** Structures of azo dye compounds (1a–1d) showing anti-mycobacterial activity.
2.2. Anticancer Activity

The photochemistry and the anti-tuberculosis activity of the in vitro azo compounds discussed above yielded good results, so their anticancer activity was also studied. An MTT test was performed for cell proliferation, and for this reason, different human cancer cell lines were used, such as chronic myeloid leukaemia (K562), lung carcinoma (A549), colon (HCT116), and T-lymphocyte (Jurkat) cell lines. Table 1 shows their anticancer activity results. Data revealed that K562, Jurkat, and A549 cell lines containing various synthesized azo compounds displayed fair in vitro results (IC$_{50}$ > 50). However, on the other hand, in comparison with other human cell lines, the HCT116 cell line showed relatively good activity in the presence of various compounds [46].

Table 1. Anticancer activities of azo compounds (1a–d).

| Compounds | HCT116 | IC$_{50}$ (µM) A549 | Jurkat | K562 |
|-----------|--------|---------------------|--------|------|
| 1a        | 34.65 ± 0.35 | >50                | >50    | >50  |
| 1b        | >50     | >50                 | >50    | >50  |
| 1c        | 43.33 ± 0.14 | >50                | >50    | >50  |
| 1d        | 48.19 ± 0.31 | >50                | >50    | >50  |

2.3. Therapeutic and Biological Applications

Various applications, such as anti-inflammatory, antibacterial, analgesic, antiviral, antipyretic, and anti-convulsant activities, belonged to 3-aminopyrroles derivatives, which are considered an essential family of compounds [47]. Thiophene compounds also play a significant role as agrochemicals [48,49], anti-avian influenza virus (H5N1), anti-tubercular, anti-breast cancer agents, AMPK activators, HIV, and multi-target kinase inhibitors [50].

The majority of roles, including serving as precursors for different biological molecules or connecting to various sulphur and nitrogen heterocycles, are imparted by some structural units combined to form a 2-aminothiophene product. Apart from this, UV-visible absorption and fluorescence of these compounds make them important for biological purposes. Thiophene derivatives can be used explicitly as valuable fluorescent dyes in confocal microscopy for bio-imaging [51].

2.4. Antiparasitic Activity of Metalloporphyrins and Their Role as Potentiometric Biosensors

Metalloporphyrins, known for their β-pyrrolic substitution, are important in forming useful supramolecules such as cytochromes, haemoglobin, peroxidases, myoglobin, and catalases [52,53]. The main reason porphyrins are gaining importance in the biological world day by day is their diverse functionality along with their remarkable structural features and positive properties in the field of photochemistry and spectroscopy. The use of metalloporphyrins as potentiometric sensors is common among all other functions—for example, Mn(III)-porphyrin derivatives are being used in the chloride ion measurement in samples of human serum [54].

The increase in antiparasitic activity of porphyrins is related to the presence of electrically charged substituents on these compounds. An ultimate decrease in the oxidative damage to the mosquitoes’ larvae of genera Culex, Aedes [55,56], and Anopheles [57], while of adult flies of Ceratitis capitata, Bactrocera oleae species, and Stomoxys calcitrans [54,58] can be observed by porphyrin-based drugs. Photosensitization makes hematoporphyrin IX a powerful eco-friendly drug.

2.5. Antioxidant Activity

Disordered physiological processes such as neurodegenerative disorders are studied by reactive nitrogen and oxygen species or heterocyclic compounds [59]. Neuroprotection involves an option of antioxidant therapy, so antioxidants can be described as compounds capable of searching for free radicals. Discussing specific fluorescent heterocycles shown
in Figure 2 such as (3s,5s,7s)-N-(2,4-dinitrophenyl)adamantan-1-amine (2a), N-((3s,5s,7s)-adamantan-1-yl)-6-(dimethylamino)-naphthalene-2-sulfonamide (2b), 2-(adamantan-1-yl)-2H-isoinole-1-carbonitrile (2c), provide us a guide to the pharmacological industry as they are of great interest as antioxidant agents [60].

![Figure 2](image)

**Figure 2.** Structures of compounds (2a–2c) having antioxidant activities.

### 2.6. Neuroprotective Agents

In addition to antioxidant properties, fluorescent heterocyclic aminoadamantane compounds exhibit neuroprotection and can serve as active compounds in search of potential therapeutics. Aside from their medical significance, many of these compounds are yet to be studied for their toxicity in humans. With further pharmacological studies and the development of fluorescent displacement, aminoadamantane derivatives can be used for radio ligand binding and neurodegenerative process explorations. In the biological and pharmaceutical industries, the function of these fluorescent heterocyclic compounds as neuro-protective drugs should be further investigated as they have encouraging physical and chemical properties and can also be used as fluorescent ligands [60].

### 2.7. Bioorganic Activity of 1,4-Dihydropyridines

The 1,4-dihydropyridines compounds are highly important as they are considered beneficial for bioorganic, synthetic, and therapeutic chemistry [61]. In biological systems, these compounds show an interesting reduction in strained ring systems such as epoxides, conjugated olefins, and carbonyls, etc., and also in unsaturated functional groups. Their unique ability involves coenzyme reduced nicotinamide adenine dinucleotide (NADH). It is said that nifedipine, belonging to a class of 1,4-dihydropyridine, shows photo toxicity. The oxidation and photo-oxidation processes of 1,4-dihydropyridines are being investigated due to their large demand and interest [62].

### 2.8. Antihypertensive and Antibacterial Activity

In this work, an antihypertensive agent 2-(2,6-dichlorobenzylidenehydrazino)-1,4,5, 6-tetrahydropyrimidine hydrochloride (3) (OT-24) was synthesized as the anti-isomer (E-isomer) by the experimentation of the nuclear Overhauser effect (NOE) and, by a process of irradiation with ultraviolet light in an aqueous or methanolic solution, it was instantly converted to its syn-isomer (Z-isomer). Not long ago, the compound (Z)-2-(2-(2, 6-dichlorobenzylidene)hydrazinyl)pyrimidine (4) and its related 2-benzylidenehydrazinopyrimidine derivatives exhibited remarkable antibacterial activity as shown below in Figure 3 [63].

### 2.9. Anti-Microbial, Antifungal and Antitumor Activities of Metal N-Heterocyclic Carbene Complexes

The ionic silver complexes such as AgNO₃ attracted great attention due to their increased stability, which was considered favorable for antimicrobial activity. Then, silver N-Heterocyclic Carbene (NHC) complexes were encapsulated, by electro-spinning, into polymers. This change led to an increase in their antifungal and bacteriostatic potential. Additionally, the anticancer activity of metal–NHC complexes has been reviewed and
reported recently. The complexes showed cytotoxicity whenever a metal was bound to an NHC ligand. Cisplatin, in particular, was outshone when metals such as silver, copper, palladium, and gold formed complexes and displayed significant antitumor activities as in Figure 4 given below—compounds such as bis(1-benzyl-3-(tert-butyl)-2,3-dihydro-1H-imidazol-2-yl)palladium(IV) chloride (5), (1,3-dimesityl-2,3-dihydro-1H-imidazol-2-yl)copper(II) chloride (6) and (1,3-dipropyl-2,3-dihydro-1H-imidazol-2-yl)silver(II) chloride (7), respectively [64].

![Figure 3](image3.png)

**Figure 3.** Compounds (3 and 4) with anti-hypertensive and antibacterial activities.

![Figure 4](image4.png)

**Figure 4.** Structures of metal complexes of N-heterocyclic carbene compounds (5–7).

2.10. *Anti-Malarial, Anti-HIV, and Antibacterial Activities of Carbazoles*

Collins and co-workers designed a method for the synthesis of a carbazole heterocycles family. Currently, this work is being extended by the same group using a different technique of photochemistry and two-step continuous-flow processes to achieve a more complicated carbazole structure [65]. A diverse range of carbazoles can be made using photochemical decomposition of azides. These carbazoles, when transformed into family alkaloid clausine C, are immensely important from a biological perspective as anti-HIV, antibacterial, and antimalarial agents, while carprofen (2-(9H-fluoren-2-yl) propanoic acid) is important as an anti-inflammatory agent, as shown below in Figure 5 [66].

![Figure 5](image5.png)

**Figure 5.** Structure of carprofen with anti-inflammatory activities.
2.11. 1,2,4-Oxa-diazoles Activity as Peptidomimetics and Bioisosteres

Because of their pharmaceutical roles, 1,2,4-oxadiazole derivatives are gaining importance. The photo-reactivity of particular 1,2,4-oxadiazoles significantly depends upon the perfluoroalkyl group [67]. Among various fluorinated five-membered heterocycles, a number of properties exhibited by 1,2,4-oxadiazoles were known to be dependent on a functional group present at C(3) position. Due to their having great importance in the pharmaceutical industry, 1,2,4-oxadiazoles have been used as bioisosteres for esters and amides and as peptidomimetics, while 3-amino derivatives of these compounds were shown to be powerful and effective muscarinic agonists [68].

2.12. Anti-Microbial Activity of 2-Chloro-5-methylpyridine-3-olefin Derivatives

In modern molecular photobiology and photochemistry, photochemical E/Z isomerization is greatly valued. To synthesize 2-chloro-5-methylpyridine-3-olefin derivatives (8a–e), 2-chloro-5-methylnicotinaldehyde can be used, and their E→Z (9a–e) isomers were studied. It was seen that the triplet excited state showed better E (trans) →Z (cis) isomerization compared to the singlet excited state. As pointed out by fluorescence studies, these isomerizations involved a polar singlet excited state or transfer of charge. As shown in Figure 6, 2-chloro-5-methylpyridine-3-olefin derivatives (8a–e) and their E→Z (9a–e) isomeric compounds were monitored, and they showed moderate anti-microbial activity [69].

![Figure 6. Structures of compounds (8a–e and 9a–e) showing anti-microbial activity.](image)

2.13. Antitumor Activity

A new class of amidino- and cyano-substituted naphtha [2,1-β] furans and naphtha [2,1-β] thiophenes were developed. These compounds were found to exhibit antitumor activity, served as DNA intercalators, and, in addition, were somehow linked to thienobenzofurans, naphthofurans, benzothiophene, and naphthothiophenes [70].

2.14. Antioxidant Activity of Halogenated β-Carbolines

Under photo-induced oxidative stress, β-carbolines (βCs) were considered good structures to show antioxidant activity. The antioxidant properties were further explored to understand the different biological functions of β-carbolines [71].

2.15. Antioxidants and Various Other Important Roles

Flavonoids are associated with stable radicals’ formation and instant oxidation and are known to protect from damage caused by free radicals, and they have a polyphenolic nature with antioxidant activity. The damage caused by free radicals was caused by various metabolic processes and singlet oxygen produced by the photolytic processes in living organisms [72]. Flavonoids also hold a grip on different biological impacts; when ultraviolet β-radiations cause damage, flavonoids are used to protect against them. These compounds also reduce cholesterol absorption and improve blood flow [73] (Table 2). The molecules that could not be accessed by conventional chemistry were now achieved by photochemical transformations and the synthesis of flavonoids. Another milestone achieved in this class
of compounds was better photochemistry and photostability of flavonoids, which resulted in their increased use as food additives for health purposes and as important constituents of black tea, adhesives, and red wine on the commercial scale [74].

Table 2. Heterocyclic compounds and their properties.

| Compounds                                      | Biological Properties                                      | References |
|------------------------------------------------|------------------------------------------------------------|------------|
| 1 Azo dye compounds (1a–d)                    | Anti-bacterial, Anti-tuberculosis, Anticaner, Anti-inflammatory, Antibacterial | [5,46]     |
| 2 3-aminopyrroles derivatives Thiophene compounds | Analgesic, Antiviral, Antipyretic, Anti-convulsant       | [47,50]    |
| 3 2-aminothiophene product                    | Bio-imaging, Photochemistry and spectroscopy           | [51]       |
| 4 Metalloporphyrins                           | Phototherapy and spectroscopy, Antiparastatic           | [54–56]    |
| 5 Fluorescent heterocycles (2a–c) Amino adamantane compounds | Antioxidant, Neuroprotection                            | [60]       |
| 6 Dihydropyridines (3 and 4)                  | Antihypertensive agents, Cardiovascular protection, Anti-microbial | [61–63]    |
| 7 Metal N-heterocyclic carbine complexes (5–7) | Antifungal, Anticaner, Photo-reactivity                | [64]       |
| 8 Oxadiazole derivatives                      | Peptidomimetics, Bioisosteres                           | [67,68]    |
| 9 2-chloro-5-methylpyridine-3-olefin derivatives (8a–e), (9a–e) | Photobiology, Photochemistry                           | [69]       |
| 10 Naphtha furans and thiophenes              | Antitumor                                                | [70]       |
| 11 Halogenated β-carbolines                   | Antioxidant, Antioxidants                               | [71]       |
| 12 Flavonoids                                 | Reduced cholesterol absorption, Improved blood flow, Photochemistry and Photostability, Antitumor | [72–74]    |
| 13 Phthalocyanines                            | Photodynamic therapy, Drug delivery systems            | [75,76]    |
| 14 Coumarins and phenanthridines              | Light-sensitive properties, Dyes and DNA targeting agents, Fluorescence, Chemosensing, Fluorescent probes for bacterial and tumour cells | [77,78]    |
| 15 Quinolones, quinolines and their derivatives (10a–b), (11a–b), (12a–b), (13a–c) | Metal ions detection, Fluorescent markers, Optical brighteners, Luminophores, UV absorbers, Colourants, Chemosensing, Fluorescent probes, Fluorescence | [79–83]    |
| 16 Imidazole pyridine derivatives (14a–e)      | Fluorescence, Fluorescent probes                        | [84,85]    |
| 17 Crown ethers (15a–b)                       | Fluorescence quenching and enhancement, Chelation of alkali metal cations | [86]       |
Table 2. Cont.

| Compounds                          | Biological Properties                          | References |
|------------------------------------|------------------------------------------------|------------|
| 18 Benzothiazole crown ethers (16a–c) | Chemosensors, Fluorescence-based metal ion sensors, Quenching effects, Fluorescent enhancement | [87]       |
| 19 14-crown-4 derivatives (17a–c)  | Lithium-ion extraction, Antiplasmodial, Trypanocidal, Anti-protozoans, Antibacterial activities | [88]       |
| 20 Naphthoquinones                 | Antiplasmodial, Trypanocidal, Anti-protozoans, Antibacterial activities | [89]       |
| 21 Nitro-heterocycle               | Antifungal, Anticancer, Anti-psychotic, Antifungal, Anti-tumour, Anti-microbial, Antibacterial | [90]       |
| 22 Imidazothiazoles                | Antifungal, Antibacterial, Anticancer | [91]       |
| 23 N-Heterocyclic Complexes        | Antifungal, Antimicrobial | [92]       |

2.16. Photodynamic Therapy of Phthalocyanines

Long ago, an alternative and useful therapy to treat various diseases involved exposing dyes to visible light to inactivate the photodynamic activity of biological systems. Photodynamic therapy (PDT), which destroys tumors and keeps normal tissues safe, works in the presence of molecular oxygen with light and a photosensitizing drug (dye) to obtain a therapeutic effect. Phthalocyanines (Pcs), a class of photosensitizers, are heterocyclic compounds that form chelate complexes with metal cations and consist of nitrogen atoms being used as bridges to link four benzoindole nuclei. Phthalocyanines have been successfully used by incorporating them into liposome membranes and in various other drug delivery systems, including cyclodextrins and oil emulsions systems [75].

2.17. Drug Activity and DNA Targeting Activity of Coumarins and Phenanthridines

By incorporating a suitable functional group in phenanthidine moiety, the role of photo-responsive chromophores was easily determined by coumarin and phenanthidine-fused scaffold, which were believed to have a significant impact on the development of organic molecules, specifically on novel coumarin and phenanthridines. This belief was the basis of intrinsic fluorescence properties of coumarin and redox- and light-sensitive properties acquired by phenanthridine derivatives. Coumarins and phenanthridines come under the two major divisions of heterocycles, having a wide range of applications in various fields such as drugs [76], dyes, and DNA targeting agents [77,78].

2.18. Applications of Fluorescent Quinolones, Quinolines and Their Derivatives

The importance of quinolines is increasing due to their renowned fluorescent compounds and their use as fluorescence probes in chemosensors [79]. Some compounds show eminent fluorescent properties such as substituted 4-trifluoromethylquinolones (11a), 4-cyanoquinolones (11b), and 3,4-dicyanoquinolones (11c) which are derived from quinolin-2-one (10a) and 4-hydroxyquinolin-2-ones (10b) as shown below in Figure 7, respectively [80].

In addition, compounds in Figure 8, 12a–f, were also found to exhibit fluorescence and used as excellent fluorescent probes for exposure to bacteria [81], tumor cells [93], or cysteine present in living cells.
Along with the above-mentioned applications, quinoline derivatives were also used to detect metal ions as fluorescent probes. Protein detection was considered an essential function performed by two compounds (13a–b) of 4-hydroxyquinolin-2-one dyes (Figure 9), which contained 4-diethylamino-2-hydroxyphenyl substituents and displayed high emission with bright fluorescence [82]. The role of these quinoline and quinolone derivatives as fluorescent markers, optical brighteners, luminophores, UV absorbers, and colorants for most biomolecules was determined [83].

2.19. Photochemical Applications of Imidazo[1,2-a]pyridine Derivatives

Some derivatives of imidazo[1,2-a]pyridine and their imidazo[1,2-a]pyridinium salts were used to prepare styryl dyes as these are well-known fluorescent compounds [84] and
the function of peripheral benzodiazepine receptor (PBR) was performed by imidazopyridine-7-nitrofurazan conjugates known for their use as fluorescent probes [85]. The area of photochemistry involves a wide range of high technology applications of highly fluorescent heterocyclic compounds pyrido[2',1':2,3]imidazo[4,5-b]quinoline-12-yl cyanides as shown in Figure 10 [94].

![Figure 10. Structures of compounds (14a–14e) showing photochemical activity.](image)

2.20. Importance of Some Crown Ethers in Physical and Biochemistry

Several significant functions such as enhancement of crown ether-naphthalene derivatives by alkali metal ions and fluorescence quenching were reported by Sousa, but the reason for this fluorescence enhancement between 1,8-naphtho-21-crown-6 (15a) and K⁺ (or Rb⁺) remained unidentified, with their structures shown in Figure 11. This fluorescence enhancement in dibenzo-18-crown-6 (15b) in alcohol involved the chelation of alkali metal cations and depended upon their atomic number M⁺. In addition, higher temperatures (300 K) and smaller viscosity were also found to be responsible for fluorescence enhancement. The main reason for this enhancement was unknown, but experiments showed that the formation of planar or semi-planar structures in these types of complexes with a large ring size was comparatively harder to accomplish [86]. Physical chemistry and biochemistry are two major fields in which these studies hold very important places.

![Figure 11. Structures of dibenzo-18-crown-6 (DC) and 1,8-naphtho-21-crown-6 ether (15a–15b).](image)
2.21. Application of Benzothiazole Crown Ethers as Metal Ion Sensors

Biological and environmental-related cations were considered hard to detect, but this was made possible by the most sensitive technique of fluorescence chemosensors. A few examples of such chemosensors or fluorescence-based metal ion sensors included benzothiazole fluorophore crown ethers, as shown in Figure 12 (16a–c). Apart from this metal ion sensing activity, the presence of nitrogen of the benzothiazole component provided extra binding capacity and so was considered of great interest as benzothiazole moiety was placed at ortho positions with respect to the crown ether. There were also chances of electrostatic interaction through ion–dipole interaction between the nitrogen ligand of benzothiazole moiety and alkali metal ions [87]. If salt concentrations were higher, quenching effects could be experienced and all these factors could lead to initial fluorescent enhancement.

![Figure 12. Structures of benzothiazole crown ethers (16a–16c).](image)

2.22. Use of Fluorescent 14-Crown-4 Derivatives in Lithium-Ion Extraction

Lithium-ion extraction was attainable by some vital chromogenic 14-crown-4 (1,4,8,11-tetraoxacyclotetradecane) derivatives including crown p-nitrophenol 17a and crown p-aminophenol 17b type chromophores shown below in Figure 13. Extraction, fluorimetry, and spectrophotometry of lithium was achieved by a new fluorescent derivative 14-crown-4, 6-dodecyl-6-[2-hydroxy-5-(1,7-naphthalenedi-carboximido)benzyl]-1,4,8,11-tetraoxacyclotetradecane 17c, which contained a p-(1,8-naphthalenedicarboximido) phenol moiety. Thus, the lithium-ion was selectively determined for extraction, fluorimetry, and spectrophotometry by this new 14-crown-4 derivative [88].

2.23. Biological Activity of Naphthoquinones

Some naphthoquinones show antiplasmodial and trypanocidal activities. These were tested by the cyclo-voltammetric activities of naphthoquinones. Many of the naphthoquinones show anticancer, anti-protozoan, and antibacterial activities (Table 2). In chemotherapy, they are the second most widely used heterocycles. Intercalation of bioactive oxygen in DNA double helix via reduction shows anticancer properties [89].
Nitro-heterocyclic medications have long been employed as antibacterial, antifungal, and anticancer agents. Newer hypoxic tumor variants have received considerable interest. To be fatal, these drugs must decrease nitro groups, which is difficult in well-oxygenated cells. Hypoxia or anoxia makes them more poisonous and ineffective. In these conditions, they are more harmful and less effective. The electrochemical behavior of several nitro compounds was studied and compared. Some of the drugs selected include misonidazole, metronidazole, ornidazole, nitropyrazole, nitrofuran, and three nitrobenzenoid compounds. Their structures and reduction potentials vary, influencing their biological function [90].

People who study the isosteric-related heterocycles, such as pyrrolothiazoles, imidazothiadiazoles, and imidazotriazoles, might want to look at how they work to treat different diseases, i.e., imidazothiazole has anti-psychotic, antifungal, anti-tumor, and anti-microbial properties, as well [91] (Table 2).

The N-based heterocycles form complexes with silver and copper metals, showing antibacterial, anticancer, antifungal, and antimicrobial activities. Their XRD shows the structure as shown in Figure 14 [92].
3. Conclusions

A large number of biologically important compounds contain the necessary conjugated double bond systems and are, therefore, potentially fluorescent. These include crown ether and $N$-containing heterocyclic compounds. Phosphorescence and fluorescence heterocyclic compounds, sometimes referred to as luminous materials, have received considerable attention because of their potential in various functional applications in organic electronics and/or optoelectronics and as materials of interest in pharmacology. These have various applications in the medicinal field as antioxidant, antimalarial, antitumor, anti-microbial, and antifungal agents. Quinolines have attracted the attention of scientists because of their uses in high-tech applications. Azafluoranthenes heterocyclic isomers may be explored as innovative, effective dyes for luminous or electroluminescent applications. Pyrene and its derivatives are often used as fluorescent probes in micellar systems for determining micro polarity, microviscosity, and aggregation number. More recently, heterocyclic azo compounds such as benzothiazole, pyrazole, and thiazole have been employed in electrochemical applications, biological applications, nonlinear optics, and structure–activity relationships [SAR]. The employment of fluorophores, including organic chromophores and crown ethers, which have high selectivity, sensitivity, and stability constants, opens up new avenues for research.

Author Contributions: The authors confirm their contribution to the paper as follows: Study conception and design: S.S.u.H. and S.B. Data collection: F.U. and S.U. Manuscript writing, R.N.P. revisions: M.F.A.K., M.M., M.F.u.R. and F.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors thank the University of Oradea, Oradea, Romania, for financial support in publishing this paper.

Conflicts of Interest: The authors declare no conflict of interest.
27. Yang, W.; Zhang, H.; Liu, Y.; Tang, C.; Xu, X.; Liu, J. Rh(iii)-catalyzed synthesis of dibenz[b,d]pyran-6-ones from aryl ketone O-acetyl oximes and quinones via C-H activation and C-C bond cleavage. *RSC Adv.* 2022, 12, 14435–14438. [CrossRef]

28. Zhang, J.; Lv, J.; Wang, J. The crystal structure of (E)-1-(4-aminophenyl)-3-(p-tolyl)prop-2-en-1-one, C6H15NO. *Z. Krist.—New Cryst. Struct.* 2022, 237, 385–387. [CrossRef]

29. Jarolímová, Z.; Vishe, M.; Lacour, J.; Bakker, E. Potassium ion-selective fluorescent and pH independent nanosensors based on functionalized polyether macrocycles. *Chem. Sci.* 2016, 7, 525–533. [CrossRef]

30. Li, Y.; Yang, H.R.; Zhao, Q.; Song, W.C.; Han, J.; Bu, X.H. Radiometric and selective fluorescent sensor for Zn2+ as an "off-on-off" switch and logic gate. *Inorg. Chem.* 2012, 51, 9642–9648. [CrossRef]

31. Valeur, B.; Leray, I. Design principles of fluorescent molecular sensors for cation recognition. *Coor. Chem. Commun.* 2000, 205, 3–40. [CrossRef]

32. Kapoor, S. Fluorescence properties of crown ethers with phenylbenzoazole pendant group. *Chem. Phys. Lett.* 2005, 408, 290–294. [CrossRef]

33. Li, J.; Yim, D.; Jang, W.; Yoon, J. Chem Soc Rev Recent progress in the design and applications of fluorescence probes containing crown ethers. *Chem. Soc. Rev.* 2016, 46, 2437–2458. [CrossRef] [PubMed]

34. Erk, C. Cation Recognition with Fluorophore Crown Ethers *Ind. Eng. Chem. Res.* 2000, 39, 3582–3588. [CrossRef]

35. Lou, X.Y.; Yang, Y.W. Manipulating Aggregation-Induced Emission with Supramolecular Macrocycles. *Adv. Opt. Mater.* 2018, 6, 1800668. [CrossRef]

36. Ji, X.; Dong, S.; Wei, P.; Xia, D.; Huang, F. A novel diblock copolymer with a supramolecular polymer block and a traditional polymer block: Preparation, controllable self-assembly in water, and application in controlled release. *Adv. Mater.* 2013, 25, 5725–5729. [CrossRef]

37. Li, B.; He, T.; Fan, Y.; Yuan, X.; Qiu, H.; Yin, S. Recent developments in the construction of metallacalycle/metallacage-cored supramolecular polymers: Via hierarchical self-assembly. *Chem. Commun.* 2019, 55, 8036–8059. [CrossRef] [PubMed]

38. Calus, S.; Gondek, E.; Danel, A.; Jarosz, B.; Pokladko, M.; Kityk, A.V. Electrofluorescence of 6-R-1,3-diphenyl-1H-pyrazolo[3,4-b]quinoline-based organic light-emitting diodes (R = F, Br, Cl, CH3, C2H3 and N(C6H5)2). *Mater. Lett.* 2007, 61, 3292–3295. [CrossRef]

39. Yan, H.; Cui, P.; Liu, C.; Yuan, S. Molecular Dynamics Simulation of Pyrene Solubilized in a Sodium Dodecyl Sulfate Micelle. *Langmuir* 2012, 28, 4931–4938. [CrossRef]

40. Gąsiorowski, P.; Danel, K.S.; Matusiewicz, M.; Uchacz, T.; Kityk, A.V. From pirazolquinolines to annulated azylene dyes: UV/Vis spectroscopy and quantum chemical study. *J. Lumin.* 2010, 130, 2460–2468. [CrossRef]

41. Stites, T.E.; Mitchell, A.E.; Rucker, R.B. Physiological importance of quinone synthase and the O-quinone family of cofactors. *J. Nutr.* 2000, 130, 719–727. [CrossRef]

42. Castro, M.C.R.; Schellenberg, P.; Belsley, M.; Fonseca, A.M.C.; Fernandes, S.S.M.; Raposo, M.M.M. Design, synthesis and evaluation of redox, second order nonlinear optical properties and theoretical DFT studies of novel bithiophene azo dyes functionalized with thiadiazole acceptor groups. *Dye. Pigment.* 2012, 95, 392–399. [CrossRef] [PubMed]

43. Beyzaei, H.; Aryan, R.; Moghaddam-Manesh, M.; Ghassami, B.; Karimi, P.; Samareh Delarami, H.; Sanchooli, M. Evaluation and structure-activity relationship analysis of a new series of 4-imino-5H-pyrazolo[3,4-d]pyrimidin-5-amines as potential antibacterial agents. *J. Mol. Struct.* 2017, 1144, 273–279. [CrossRef]

44. Raposo, M.M.M.; Castro, M.C.R.; Fonseca, A.M.C.; Schellenberg, P.; Belsley, M. Design, synthesis, and characterization of the electrochemical, nonlinear optical properties, and theoretical studies of novel thiophenylpyrrole azo dyes bearing benzoazole acceptor groups. *Tetrahedron* 2011, 67, 5189–5198. [CrossRef]

45. Huang, X.; Groves, J.T. Oxygen Activation and Radical Transformations in Heme Proteins and Metalloporphyrins. *Chem. Rev.* 2018, 118, 2491–2553. [CrossRef]

46. Maliyappa, M.R.; Keshavaaya, J.; Mallikarjuna, N.M.; Pushpavathi, I. Novel substituted aniline based heterocyclic dispersed azo dyes coupling with 5-methyl-2-(6-methyl-1,3-benzothiazol-2-yl)-2, 4-dihydro-3H-pyrazol-3-one: Synthesis, structural, computational and biological studies. *J. Mol. Struct.* 2019, 1205, 127576. [CrossRef]

47. Khan, F.A.; Ali, G.; Rahman, K.; Khan, Y.; Ayaz, M.; Mosa, O.F.; Nawaz, A.; Hassan, S.S.U.; Bungau, S. Efficacy of 2-Hydroxyflavanone in Rodent Models of Pain and Inflammation: Involvement of Opioidergic and GABAergic Anti-Nociceptive Mechanisms. *Molecules* 2022, 27, 5431. [CrossRef]

48. Mahmood, F.; Khan, J.A.; Mahnashi, M.H.; Jan, M.S.; Javed, M.A.; Rashid, U.; Sadiq, A.; Hassan, S.S.U.; Bungau, S. Anti-Inflammatory, Analgesic and Antioxidant Potential of New (2S,3S)-2-(4-isopropylbenzyl)-2-methyl-4-nitro-3-phenylbutanals and Their Corresponding Carboxylic Acids through In Vitro, *In Silico* and In Vivo Studies. *Molecules* 2022, 27, 4068. [CrossRef]

49. Muhammad, I.; Luo, W.; Shoaib, R.M.; Li, G.L.; Hassan, S.S.U.; Yang, Z.H.; Xiao, X.; Tu, G.L.; Yan, S.K.; Ma, X.P.; et al. Guanaine-type sesquiterpenoids from Cinnamomum migao H. W. Li: And their anti-inflammatory activities. *Phytochemistry* 2021, 190, 112850. [CrossRef] [PubMed]

50. Rashad, A.E.; Shamroukh, A.H.; Abdel-megeid, R.E.; Mostafa, A.; El-shesheny, R.; Kandeil, A.; Ali, M.A.; Banert, K. European Journal of Medicinal Chemistry Synthesis and screening of some novel fused thioephene and thienopyrimidine derivatives for anti-avian in fl uenza virus (H5N1) activity. *Eur. J. Med. Chem.* 2010, 45, 5251–5257. [CrossRef]

51. Baleiz, C. Synthesis and fluorescence properties of aminocyanopyrrole and aminocyanothiophene esters for biomedical and bioimaging applications. *J. Mol. Struct.* 2020, 1209, 127974. [CrossRef]
52. Imran, M.; Ramzan, M.; Qureshi, A.K.; Khan, M.A.; Tariq, M. Emerging Applications of Porphyrins and Metalloporphyrins in Biomedicine and Diagnostic Magnetic Resonance Imaging. Biosensors 2018, 8, 95. [CrossRef]

53. Zhang, X.; Qu, Y.; Liu, L.; Qiao, Y.; Geng, H.; Lin, Y.; Zhao, J. Homocysteine inhibits pro-insulin receptor cleavage and causes insulin resistance via protein cysteine-homocysteinylation. Cell Rep. 2021, 37, 109821. [CrossRef]

54. Garcia, C.R.S.; Deda, D.K.; Iglesias, B.A.; Alves, E.; Araki, K. Porphyrin Derivative Nanoformulations for Therapy and Antiparasitic Agents. Molecules 2020, 25, 2080. [CrossRef]

55. Awad, H.H.; El-tayeb, T.A.; Abd El-aziz, N.M.; Abdelkader, M.A. A Semi-field Study on the Effect of Novel Hematoporphyrin Formula on the Control of Culex pipiens Larvae. J. Agric. Soc. Sci. 2008, 85–88.

56. Lucantonii, L.; Magaraggia, M.; Lupidi, G.; Ouedraogo, R.K.; Esposito, F.; Fabris, C.; Jori, G.; Habluetzel, A. Novel, Meso-Substituted Cationic Porphyrin Molecule for Photo-Mediated Larval Control of the Dengue Vector Aedes aegypti. J. Pntd. 2011, 5, e1434. [CrossRef]

57. Fabris, C.; Kossivi, R.; Coppelotti, O.; Dabiré, R.K.; Diabaté, A.; Di, P.; Guidolin, L.; Jori, G.; Lucantonii, L.; Lupidi, G.; et al. Acta Tropica Efficacy of sunlight-activatable porphyrin formulations on larvae of Anopheles gambiae M and S molecular forms and An arabiensis: A potential novel biolarvicide for integrated malaria vector control. Acta Trop. 2012, 123, 239–243. [CrossRef]

58. Ben Amor, T.; Jori, G. Sunlight-activated insecticides: Historical background and mechanisms of phototoxic activity. Insect Biochem. Mol. Biol. 2000, 30, 915–925. [CrossRef]

59. Nishida, J.; Kawabata, J. DPPH Radical Scavenging Reaction of Hydroxy- and Methoxychalcones. Biosci. Biotechnol. Biochem. 2016, 80(5), 193–202. [CrossRef]

60. Joubert, J.; Van Dyk, S.; Green, I.R.; Malan, S.F. Bioorganic & Medicinal Chemistry Synthesis and evaluation of fluorescent heterocyclic aminoaromatransfenes as multifunctional neuroprotective agents. Bioorg. Med. Chem. 2011, 19, 3935–3944. [CrossRef]

61. Hassan, S.S.U.; Abdel-Daim, M.M.; Behl, T.; Bungau, S. Natural Products for Chronic Diseases: A Ray of Hope. Molecules 2022, 27, 5573. [CrossRef] [PubMed]

62. Memarian, H.R.; Mirjafari, A. Solid state photochemistry of 1,4-dihydropyridines. Bioorg. Med. Chem. Lett. 2005, 15, 3423–3425. [CrossRef]

63. Mishra, R.; Siddiqui, A.A.; Husain, A.; Rashid, M.; Prakash, A.; Tailang, M.; Kumar, M.; Srivastava, N. Synthesis, characterization and antihypertensive activity of some new substituted pyridazine derivatives. J. Chin. Chem. Soc. 2011, 56, 856–859. [CrossRef]

64. Xu, S.; Tao, H.; Cao, W.; Cao, L.; Lin, Y.; Zhao, S.-M.; Xu, W.; Cao, J.; Zhao, J.-Y. Ketogenic diets inhibit mitochondrial biogenesis and induce cardiac fibrosis. Signal Transduct. Target. Ther. 2021, 6, 54. [CrossRef] [PubMed]

65. Hassan, S.S.U.; Muhammad, I.; Abbass, S.Q.; Hassan, M.; Majid, M.; Jin, H.Z.; Bungau, S. Stress driven discovery of natural products from actinobacteria with anti-oxidant and cytotoxic activities including docking and admet properties. Int. J. Mol. Sci. 2021, 22, 11432. [CrossRef]

66. Song, K.; Wu, D. Shared decision-making in the management of patients with inflammatory bowel disease. World J. Gastroenterol. 2022, 28, 2092–3100. [CrossRef]

67. Buscemi, S.; Pace, A.; Pibiri, I. Fluorinated heterocyclic compounds: An assay on the photochemistry of some fluorinated 1-oxa-2-azoles: An expedient route to fluorinated heterocycles. J. Fluor. Chem. 2004, 125, 165–173. [CrossRef]

68. Buscemi, S.; Pace, A.; Piccionello, A.P.; Pibiri, I.; Vivona, N. Fluorinated heterocyclic compounds. A photochemical synthesis of 3-amino-5-perfluoroaryl-1,2,4-oxadiazoles. Heterocycles 2001, 57, 5865–5871. [CrossRef]

69. Gangadasu, B.; Ram, M.J.; Ravinder, M.; Kumar, S.B.; Kumar, K.P.; Murthy, U.S.N.; Rao, V.J. European Journal of Medicinal Chemistry Synthesis, photochemical E (trans)/Z (cis) isomerization and antimicrobial activity of 2-chloro-5-methylpyridine-3-amino-5-perfluoroaryl-1,2,4-oxadiazoles. Heterocycles 2022, 57, 10982–1100. [CrossRef]

70. Sisa, M.; Bonnet, S.L.; Ferreira, D.; Westhuizen, J.H. Solid State Photochemistry of 1,4-dihydropyridines: An expedient route to fluorinated heterocycles. J. Fluor. Chem. 2004, 125, 165–173. [CrossRef]

71. Pietta, P. Flavonoids as Antioxidants. J. Nat. Prod. 2000, 63, 1035–1042. [CrossRef]

72. Araù, Y.; Watanabe, S.; Kimura, M.; Shimo, K.; Mochizuki, R.; Kinae, N. Human Nutrition and Metabolism Dietary Intakes of Flavonols, Flavones and Isoflavones by Japanese Women and the Inverse Correlation between Quercetin Intake and Plasma LDL Cholesterol Concentration 1. J. Nutr. 2003, 133, 1967–1976. [CrossRef]

73. Arai, Y.; Watanabe, S.; Kimura, M.; Shimoi, K.; Mochizuki, R.; Kinae, N. Human Nutrition and Metabolism Dietary Intakes of Flavonols, Flavones and Isoflavones by Japanese Women and the Inverse Correlation between Quercetin Intake and Plasma LDL Cholesterol Concentration 1. J. Nutr. 2003, 133, 1967–1976. [CrossRef]

74. Kampranis, S.C.; Gornley, N.A.; Tranter, R.; Orphanides, G.; Maxwell, A.; Uni, V.; Le, L. Probing the Binding of Coumarins and Cyclohexadienones to DNA Gyrase. Biochemistry 1999, 38, 1967–1976. [CrossRef]

75. Wang, D.; Zhao, R.; Qu, Y.-Y.; Mei, X.-Y.; Zhang, Y.; Zhou, Q.; Li, Y.; Yang, S.-B.; Zou, Z.-G.; Chen, Y.-M.; et al. Colonic Lysine Homocysteinylation Induced by High-Fat Diet Suppresses DNA Damage Repair. Cell Rep. 2018, 25. [CrossRef]

76. Li, Y.; Yao, C.-F.; Xu, F.-J.; Qu, Y.-Y.; Li, J.-T.; Lin, Y.; Cao, Z.-L.; Lin, P.-C.; Xu, W.; Zhao, S.-M.; et al. APC/C(CDH1) synchronizes ribose-5-phosphate levels and DNA synthesis to cell cycle progression. Nat. Commun. 2019, 10, 2502. [CrossRef]
79. Zhang, N.; Zhao, Y.; Zhang, H.; Wang, H. Sensitive determination of aliphatic amines by high-performance liquid chromatography with a new carboxaldehyde. *J. Sep. Sci.* 2008, 31, 38–46. [CrossRef]

80. Sladlbauer, W.; Achale, A.B.; Badguraj, N.S.; Uray, G. Syntheses and Fluorescent Properties of 2-Amino Substituted 6, 7-Dimethoxy-4-(trifluoromethyl) quinolines. *J. Heterocycl. Chem.* 2009, 40, 3–8. [CrossRef]

81. Dhanapal, R.; Perumal, P.T.; Damodiran, M.; Ramprasath, C. Bioorganic & Medicinal Chemistry Letters Synthesis of quinoline derivatives for fluorescent imaging certain bacteria. *Biosig. Med. Chem. Lett.* 2012, 22, 6494–6497. [CrossRef] [PubMed]

82. Kovalska, V.B.; Volkova, K.D.; Manaev, A.V.; Yu, M.; Okhrimenko, I.N.; Traven, V.F.; Yarmoluk, S.M. Dyes and Pigments 2-Quinolone and coumarin polymethines for the detection of proteins using fluorescence. *Dye. Pigment.* 2010, 84, 159–164. [CrossRef]

83. Aly, A.A.; Ramadan, M.; Abuo-rahma, G.E.A. Quinolones as prospective drugs: Their syntheses and biological applications. *Adv. Heterocycl. Chem.* 2020, 135, 147–196. [CrossRef]

84. Kovalska, V.B.; Losytskyy, M.Y.; Kryvorotenko, D.V.; Balanda, A.O.; Tokar, V.P.; Yarmoluk, S.M. Synthesis of novel fluorescent styryl dyes based on the imidazo [1,2-a] pyridinium chromophore and their spectral-fluorescent properties in the presence of nucleic acids and proteins. *Dye. Pigment.* 2006, 68, 39–45. [CrossRef]

85. Laquintana, V.; Denora, N.; Lopedota, A.; Suzuki, H.; Sawada, M.; Serra, M.; Farmaco-chimico, D.; Orabona, V.; Sperimentale, B.; Neuroscienze, S.; et al. N-Benzyl-2-(6,8-dichloro-2-(4-chlorophenyl)imidazo[1,2-a]pyridin-3-yl)-N-(6- (7-nitrobenzo [c][1,2,5] oxadiazol-4-ylamino) hexyl) acetamide as a New Fluorescent Probe for Peripheral Benzodiazepine Receptor and Microglial Cell Visualization. *Bioconjugate Chem.* 2007, 18, 1397–1407. [CrossRef] [PubMed]

86. Kralj, M.; Tušek-Božič, L.; Frkanec, L. Biomedical Potentials of Crown Ethers: Prospective Antitumor Agents. *Chem. Med. Chem.* 2008, 3, 1478–1492. [CrossRef]

87. Mashraqui, S.H.; Kumar, S.; Vashi, D. Synthesis, Cation-Binding and Optical Spectral Studies of Photoemmitive. *J. Incl. Phenom. Macrocycl. Chem.* 2004, 48, 125–130. [CrossRef]

88. Czech, B.P.; Babb, D.A.; Son, B.; Barths, R.A. Functionalized 13-Crown-4, 14-Crown-4, 15-Crown-4, and 16-Crown-4 Compounds: Synthesis and Lithium Ion Complexation. *J. Org. Chem.* 1994, 49, 4805–4810. [CrossRef]

89. Majid, M.; Farhan, A.; Asad, M.I.; Khan, M.R.; Hassan, S.S.U.; Haq, I.-U.; Bungau, S. An Extensive Pharmacological Evaluation of New Anti-Cancer Triterpenoid (Nummularic Acid) from Ipomoea batatas through In Vitro, In Silico, and In Vivo Studies. *Molecules* 2022, 27, 2474. [CrossRef]

90. Shams ul Hassan, S.; Abbas, S.Q.; Hassan, M.; Jin, H.-Z. Computational Exploration of Anti-Cancer Potential of Guaiane Dimers from Xylopia vielana by Targeting B-Raf Kinase Using Chemo-Informatics, Molecular Docking and MD Simulation Studies. *Anti-Cancer Agents Med. Chem.* 2021, 21, 1–16. [CrossRef]

91. Fascio, M.L.; Errea, M.I.; D’Accorso, N.B. Imidazothiazole and related heterocyclic systems. Synthesis, chemical and biological properties. *Eur. J. Med. Chem.* 2015, 90, 666–683. [CrossRef] [PubMed]

92. Sayin, K.; Kariper, S.E.; Taştan, M.; Sayin, T.A.; Karakaş, D. Investigations of structural, spectral, electronic and biological properties of N-heterocyclic carbene Ag(I) and Pd(II) complexes. *J. Mol. Struct.* 2019, 1176, 478–487. [CrossRef]

93. Wu, Z. Molecular imaging of human tumor cells that naturally overexpress type 2 cannabinoid receptors using a fluorescent probe overexpress type 2 cannabinoid receptors using. *J. Biomed. Opt.* 2014, 19, 076016. [CrossRef] [PubMed]

94. Rahimizadeh, M.; Pordel, M.; Bakavoli, M.; Eshghi, H. Dyes and Pigments The synthesis of highly fluorescent heterocyclic compounds: Pyrido [2 0, 1 0: 2, 3] imidazo [4, 5-b] quinoline-12-yl cyanides. *Dye. Pigment.* 2010, 86, 266–270. [CrossRef]