Chiral Bipyridine and Terpyridine Ligands Grafted with L-Tyrosine Fragments

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Abstract: The synthesis of stable terpyridine and bipyridine frames substituted with L-tyrosine fragments is reported. These highly functionalized compounds have been prepared from the corresponding iodo, and ethynyl substituted analogs by a reaction catalyzed by low valent palladium(0), itself generated in situ from palladium(II) and CuI. A tertiary amine is required to quench the nascent acid. Complexation of the chelating part of the molecule with ruthenium(II) metal afforded redox and photoactive complexes. With the terpy-Ru complex carrying a genuine tyrosine fragment an efficient quenching reaction ($k_q = 2.2 \times 10^9$ s^{-1}) due to electron transfer is observed in DMF and in the presence of K_2CO_3. The blank experiment performed under the same conditions with the tyrosine-protected benzoyl ester proved that this process is inhibited. The synthetic methods reported herein provide a practical methodology to the rational design of transition metal complexes bearing different kinds of bioactive functionalities.

Key words: bipyridine, terpyridine, palladium, alkyne, tyrosine, electron transfer

Derivatized oligopyridine frameworks provide a versatile platform for creating preorganized and multifunctional ligands.[1–3] This includes 2,2':6',2''-terpyridine (terpy) and 2,2'-bipyridine (bipy) chelates which have high absorptiions in the near UV based on π-π* transitions. A wide range of these structurally defined π-electronic and conjugated systems have been studied and surmised to be good candidates for electronic and optoelectronic devices.[4] Along these lines, we have been engaged in the synthesis of preorganized ligands bearing multiple coordination sites connected by acetylenic linkages.[5] Their related complexes of Ru^{II}, Os^{II}, Zn^{II}, Fe^{II} provide an unique opportunity to study vectorial energy and/or electron transfer along the main molecular axis.[6] Furthermore, by careful tailoring of the ligand it was possible to recognize and detect adventitious cations.[7] In continuation of our investigations on the electronic properties of new conjugated systems, we have now designed a hybrid system in which an alkyne substituted chromophore (luminescent label) is connected to a biomolecule (tyrosine fragment) with the goal of creating luminescent biological labels able to be intercalated in oligonucleotides (Figure).

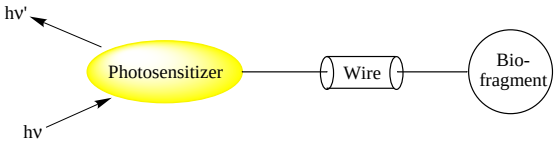

Figure Schematic representation of a luminescent label with three components: (i) a signal-generating subunit, (ii) a spacer based on wires and, (iii) an anchor group from a bioactive fragment

The choice of tyrosine (TyrZ) as chiral fragment reflected the thinking that it would act as an electron donor as reported.[8] In particular, in Photosystem II (PS II, a large membrane-bounded protein complex), light energy drives the electron transfer from water to carbon dioxide and many cofactors including tyrosine radical intermediates are involved. It is commonly accepted that a tetranuclear manganese complex is associated with the PS II core and promotes catalytic water oxidation to molecular oxygen. During this complicate and multistep process, the primary electron donor, a chlorophyll called P_{680}, is excited by light and an electron is transferred to primary electron acceptors such as pheophytin and quinones. The oxidized P_{680}^+ retrieves an electron from the TyrZ residue which then forms a neutral radical as shown in the equation below. Similar radicals are involved in enzymes, e.g. Galactose Oxidase[9] and a plethora of model systems have appeared past in the literature.[10] Mimicking electron transfer reactions of naturally occurring proteins and enzymes has attracted a lot of attention.[11]

$$TyrZ + P_{680}^+ \rightarrow Tyrz\bullet + P_{680} + H^+$$

Combination of chromophoric ruthenium fragments connected to tyrosine subunits via efficient electronic conduit such as acetylenic junction is a promising starting point for the further development of advanced models for the water-oxidizing complex in PS II, as well as to perfect artificial water oxidation catalysts. We wish to describe herein novel molecules bearing a chelating fragment (bpy or terpy) connected via an ethynyl sp-bridge to an optically pure tyrosyl moiety.

The starting material used in this protocol is the esterified analog to 3-iodo-L-tyrosine which was prepared in methanol in the presence of an excess thionyl chloride as shown in Scheme 1.

During this first step, the chloride salt **2** is formed from **1** in excellent yield.[12] It was soon established that the transformation of **2** to the corresponding amide required spe-

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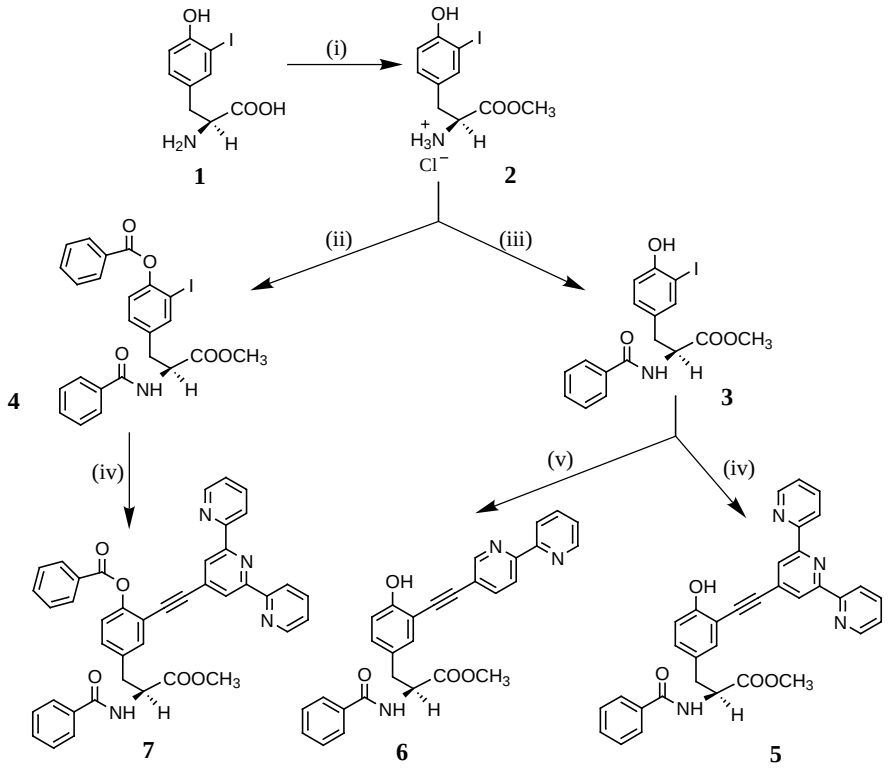


Scheme 1 (i) $SOCl_2$, MeOH, 70 °C, 92%; (ii) benzoyl chloride (2 equiv), Et_3N (6 equiv) 45 °C, 73%; (iii) benzoyl chloride (1 equiv), Et_3N (2 equiv), 45 °C, 92%; (iv) 4'-terpyOTf, $Pd(PPh_3)_2Cl_2$ (6 mol%), CuI (6 mol%), THF, *i*-Pr_2NH, r.t., 49% for **7** and 42% for **5**; (v) 5-ethynyl-2,2'-bipyridine, $Pd(PPh_3)_2Cl_2$ (6 mol%), CuI (6 mol%), THF, *i*-Pr_2NH, r.t., 57%

cial reaction conditions and the formation of the amide/ester species **3** was prone to low yield in the presence of an excess benzoyl chloride and triethylamine (Table 1).

Compound **4** bearing two esters and one amide functions is obtained with an isolated yield of 73% in the presence of two equivalents of benzoyl chloride and six equivalents of base. The optimal conditions for the preparation of **3** (89% isolated yield) requires one equivalent of benzoyl chloride and two equivalents of base. All intermediate situations provide a mixture of both compounds (Table 1). Compounds **3** ($[\alpha]_D$ +11) and **4** ($[\alpha]_D$ +17) compared to the starting material **2** ($[\alpha]_D$ –6) generate a positive Cotton effect which is responsible for the signal inversion and an increase of the rotatory power. Analogous observations have been made in the amidation of the amine function of L-tyrosine.[12]

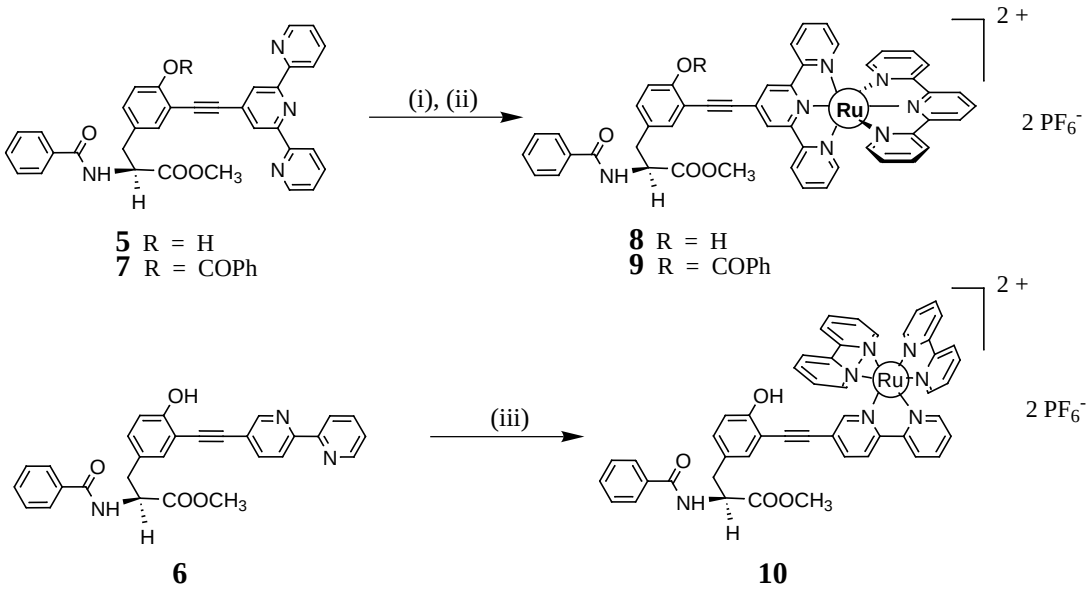
Table 1 Selected Experimental Data Concerning the Synthesis of Compounds **3** and **4**[a]

2 (mol equiv)	C_6H_5COCl (mol equiv)	Et_3N (mol equiv)	Reaction Time (h)	Isolated Yield (%) of **3** and **4**
1	1	4	4.5	31 (**3**), 22 (**4**)
1	1.5	4	6	12 (**3**), 45 (**4**)
1	1	2	20	89 (**3**)
1	2	6	8	73 (**4**)

[a] In CH_2Cl_2 at r.t.

The molecules bearing a chelating fragment (bipy or terpy) connected via an ethynyl sp-bridge to the optically pure L-tyrosyl moiety were constructed by cross-coupling the mono-protected compound **3** with either 5-ethynyl-2,2'-bipyridine[13] or 4'-ethynyl-2,2':6',2''-terpyridine[5] (Scheme 1). The diprotected compound **4** was also prepared in good yield applying the same protocol and will serve as an important test complex in subsequent photoinduced electron transfer studies. The low valent palladium(0) required for these cross-coupling reactions was generated in-situ from $Pd(PPh_3)_2Cl_2$ and CuI in the presence of a large excess of *i*-Pr_2NH which quenched the nascent acid.[14]

Complexation of the terpy-based ligands **5** and **7** was insured by reaction with $[Ru(terpy)(S)_3]^{2+}$ (S = DMSO or methanol) obtained by silver dehalogenation of $Ru(terpy)(DMSO)Cl_2$[15] in methanol. Complexation of the bipy fragment in **6** is straightforward and was carried out by reaction with $Ru(bipy)_2Cl_2 \cdot 2H_2O$[16] in ethanol (Scheme 2). The three ruthenium(II) complexes **8**–**10** display well defined π-π* absorption bands due to the bipy or terpy moieties in the UV part of the absorption spectra and intense metal-to-ligand-charge-transfer (MLCT) absorption bands with maxima at 492 nm and 452 nm respectively for the terpy and bipy complexes. Furthermore all complexes are reversibly oxidized to ruthenium(III) around 1.27 V versus the saturated calomel reference



5 R = H
7 R = COPh

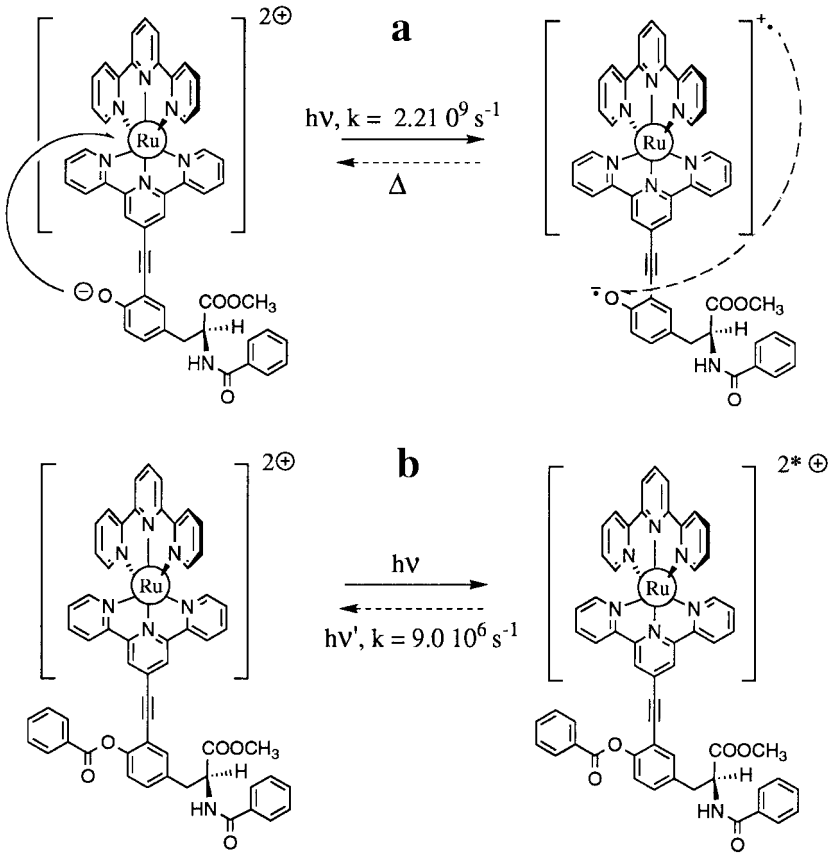
8 R = H
9 R = COPh

6

10

Scheme 2 (i) $AgBF_4$ (2 equiv.), Ru(terpy)(DMSO)Cl_2, MeOH, 80 °C; (ii) MeOH, 80 °C, 69% for **8** and 58% for **9**; (iii) Ru(bipy)$_2Cl_2 \cdot 2H_2O$, EtOH, 80 °C, 58%

electrode, while successive and reversible reduction of the terpy's occurred at *ca* –1.20 V and *ca* –1.54 V and at –1.20, –1.50 and –1.72 V for the 'Ru(bipy)$_3$' complex **10**. No apparent oxidation of the phenol group is found within the electroactive domain (until +1.50 V).[17] It is presumed that this oxidation is kinetically inhibited under the used experimental conditions.



Scheme 3 Schematic representation of: (a) the photoinduced electron transfer in compound **8** under basic conditions; (b) the photoexcitation of compound **9** under similar conditions, light is emitted during the relaxation process

Table 2 Selected Spectroscopic and Redox Data for the Ruthenium(II) Complexes[a]

Compound	λ_{abs} (nm) (ε $M^{-1}cm^{-1}$)	λ_{em} (nm)	τ_T (ns)	ϕ_{Lum} (10^{-3})	E_{Ox} (V)	E_{Red} (V)
$[Ru(terpy)_2]^{2+}$	474 (15300)	650	0.6	<0.1	1.27 ($1e^-$)	–1.27 ($1e^-$), –1.51 ($1e^-$)
8	492 (28800)	660	112	2.8	1.25 ($1e^-$)	–1.19 ($1e^-$), –1.54 ($1e^-$)
9	492 (24400)	660	110	2.5	1.27 ($1e^-$)	–1.20 ($1e^-$), –1.51 ($1e^-$)
$[Ru(bipy)_3]^{2+}$	450 (14600)	627	980	62	1.30 ($1e^-$)	–1.25 ($1e^-$), –1.52 ($1e^-$), –1.79 ($1e^-$)
10	454 (10900)	635	1100	70	1.29 ($1e^-$)	–1.20 ($1e^-$), –1.50 ($1e^-$), –1.72 ($1e^-$)

[a] In argon degassed acetonitrile, λ_{abs} for the metal-ligand-charge-transfer absorption band, λ_{em} for the emission maximum, τ_T for the triplet lifetime, ϕ_{Lum} for the emission quantum yield, E_{Ox} for the oxidation potential, E_{Red} for the sucessive reduction potentials quoted versus the saturated calomel electrode using ferrocene as internal reference E_0 Fc/Fc^+ = +0.39 V. The number of exchanged electrons is given in parentheses and tetrabutylammonium hexafluorophosphate is used as supporting electrolyte.

Preliminary photophysical results showed that these new complexes are highly emissive in solution and at room temperature, with triplet excited state lifetimes about 180 times longer for complexes **8** and **9** compared to $[Ru(terpy)_2]^{2+}$. As expected a weaker effect is observed for complex **10** when compared to $[Ru(bipy)_3]^{2+}$. Selected data are gathered in Table 2. Interestingly, in the presence of K_2CO_3 in DMF at room temperature, the lifetime of complex **8** drops dramatically short (τ = 0.37 ns), indicating that the triplet excited state is quenched by electron transfer with a estimated rate of 2.2×10^9 s^{-1} (Scheme 3). Back electron transfer to regenerate the ground state is certainly fast due to a large driving force and prevents the observation of the tyrosine radical by transcient absorption spectroscopy. Hence related complex **9** in which the phenolate is not available due to the protection with the benzoyl fragment, the quenching process is not observed. Work is in progress in order to have a deeper insight into this interesting conjugated system.

In summary, we have developed a practical method for the synthesis of L-tyrosine-substituted terpyridines and bipyridine, which avoid the drawbacks proned by more conventional methods. It is worth noting that Sonogashira coupling reaction tolerate the presence of phenol, ester and amide functions without perturbing significantly the course of the palladium-promoted catalytic reaction. In turn, these ligands are versatile targets for the construction of redox and photoactive complexes. This is of particular importance in that it represents a facile route to the preparation of chiral luminophoric fragments. The ready availability of the reagents, the overall simplicity of the procedure, the use of mild reaction conditions, and the reasonable yields obtained suggest that this methodology is an useful entry for the preparation of hybrid molecules bearing a bioactive fragment.[18,19]

3-Iodo-L-tyrosine Methyl Ester Hydrochloride (2)

To a stirred solution of **1** (1g, 3.26 mmol) in anhyd MeOH (25 mL) at 0 °C was added dropwise $SOCl_2$ (3 mL, 41.13 mmol) over 0.5 h and the mixture was heated for 3 h at 70 °C. After cooling down to r.t., Et_2O (20 mL) was added, the resultant precipitate collected by filtration, washed with Et_2O (2 × 10 mL) and dried under high vacuum; yield: 1.08 g (92%); mp 211–212 °C; $[\alpha]_D$ – 6 (*c* = 5 g/L in CH_2Cl_2).

^1H NMR (D_2O + *t*-BuOH): δ = 3.22 (m, CH_2, 2 H), 3.89 (s, OCH_3, 3 H), 4.40 (t, $^3J_{H-H}$ = 6.8 Hz, CH, 1 H), 6.98 (d, $^3J_{H-H}$ = 8.4 Hz, 1 H_{arom}), 7.20 (dd, $^3J_{H-H}$ = 8.4 Hz, $^4J_{H-H}$ = 2.2 Hz, 1 H_{arom}), 7.72 (d, $^4J_{H-H}$ = 2.2 Hz, 1 H_{arom}).

$^{13}C\{^1H\}$ NMR (D_2O + *t*-BuOH): δ = 31.1, 50.4, 50.9, 80.8, 112.4, 124.4, 127.7, 136.9, 151.8, 166.8.

FT-IR (KBr): ν = 3274 (s), 2991 (s), 2951 (s), 2879 (s), 2699 (m), 1742 (s), 1603 (m), 1579 (m), 1505 (s), 1444 (m), 1416 (s), 1347 (m), 1284 (s), 1248 (s), 1217 (s), 1141 (m), 821 cm^{-1} (m).

UV-Vis (H_2O): λ_{max} (ε, M^{-1} cm^{-1}) = 283 nm (2,300).

MS (FAB^+): *m*/*z* (nature of peak, relative intensity) = 322 ($[M - Cl]^+$, 100).

Anal. Calcd for $C_{10}H_{13}ClINO_3$ (357.6): C, 33.59; H, 3.66; N, 3.92. Found: C, 33.23; H, 3.44; N, 3.65.

***N*-Benzoyl-3-Iodo-L-tyrosine Methyl Ester (3)**

To a suspension of **2** (0.20 g, 0.56 mmol) in CH_2Cl_2 (20 mL) was added Et_3N (0.156 mL, 1.12 mmol). After dissolution (0.5 h), benzoyl chloride (0.065 mL, 0.56 mmol) was added and the mixture was stirred at r.t. for 20 h. Purification was performed by chromatography on alumina eluting with CH_2Cl_2–MeOH (0% to 2%). The analytically pure white compound was obtained after recrystallization from CH_2Cl_2–hexane affording 219 mg of **3** (92%); mp 123–124 °C; $[\alpha]_D$ + 11 (*c* = 5 g/L in CH_2Cl_2).

^1H NMR ($CDCl_3$): δ = 3.12 (m, CH_2, 2 H), 3.76 (s, OCH_3, 3 H), 5.01 (m, CH, 1 H), 5.65 (s, 1 H), 6.75 (d, $^3J_{H-H}$ = 7.3 Hz, 1 H), 6.84 (m, 2 H), 7.45 (m, 4 H), 7.71 (d, $^3J_{H-H}$ = 6.95 Hz, 2 H).

$^{13}C\{^1H\}$ NMR ($CDCl_3$): δ = 36.4, 52.6, 53.7, 84.9, 115.2, 127.0, 128.6, 129.2, 130.6, 132.0, 133.4, 139.3, 154.8, 167.4, 172.0.

FT-IR (KBr): ν = 3425 (s), 2945 (m), 2356 (w), 1738 (s), 1641 (s), 1603 (w), 1575 (w), 1535 (s), 1487 (m), 1416 (m), 1290 (m), 1219 (s), 1024 (w), 714 cm^{-1} (m).

UV-Vis (CH_2Cl_2): λ_{max} (ε, M^{-1} cm^{-1}) = 281 (2,800), 289 nm (2,500).

MS (FAB^+): *m*/*z* (nature of peak, relative intensity) = 426 ($[M + H]^+$, 100), 367 ($[M - CO_2CH_3 + H]^+$, 30).

Anal. Calcd for $C_{17}H_{16}INO_4$ (425.2): C, 48.02; H, 3.79; N, 3.29. Found: C, 47.89; H, 3.57; N, 2.99.

***N,O*-Dibenzoyl-3-Iodo-L-tyrosine Methyl Ester (4)**

This compound was prepared by following the procedure described above for **3** using **2** (200 mg, 0.56 mmol) in CH_2Cl_2 (40 mL), Et_3N (0.468 mL, 3.356 mmol) and benzoyl chloride (0.064 mL, 0.56 mmol). The mixture was stirred at r.t. for 8 h. Purification was performed by chromatography on alumina eluting with CH_2Cl_2 to afford 216 mg of **4** (73%); mp 203–204 °C; $[\alpha]_D$ +17 (5 g/L in CH_2Cl_2).

^{1}H NMR ($CDCl_3$): δ = 3.28 (m, CH_2, 2 H), 3.81 (s, OCH_3, 3 H), 5.11 (m, CH, 1 H), 6.71 (d, $^3J_{H-H}$ = 6.9 Hz, 1 H), 7.20 (m, 2 H), 7.52 (m, 5 H), 7.69 (m, 4 H), 8.26 (m, 2 H).

^{13}C{^{1}H} NMR ($CDCl_3$): δ = 36.8, 52.6, 53.5, 90.4, 123.0, 127.0, 128.6, 128.7, 129.0, 130.3, 130.4, 131.9, 133.7, 133.9, 135.7, 140.2, 150.5, 164.2, 167.0, 171.7.

FT-IR (KBr): ν = 3328 (s), 2944 (m), 2362 (w), 1733 (s), 1638 (s), 1602 (w), 1578 (w), 1527 (s), 1487 (m), 1449 (m), 1373 (m), 1320 (m), 1260 (s), 1203 (s), 1160 (m), 1081 (m), 705 cm^{-1} (m).

UV-Vis (CH_2Cl_2): λ_{max} (ε, M^{-1} cm^{-1}) = 269 nm (3,500).

MS (FAB$^+$): *m/z* (nature of peak, relative intensity) = 530 ([M + H]$^+$, 100), 426 ([M – PhCO + 2 H]$^+$, 20), 320 ([M – 2 PhCO + H]$^+$, 5).

Anal. Calcd for $C_{24}H_{20}INO_5$ (529.3): C, 54.46; H, 3.82; N, 2.65. Found: C, 54.15; H, 3.62; N, 2.47.

Ligands 5–7; General Procedure

A Schlenk flask was charged stepwise with derivatives **3** or **4** and 4'-ethynyl-2,2':6',2''terpyridine or 5-ethynyl-2,2'-bipyridine in argon degassed THF, then with $Pd(PPh_3)_2Cl_2$ (6 mol%) and CuI (6 mol%) and finally argon degassed diisopropylamine was added. The mixture was stirred for 3 d at r.t. After consumption of the starting material (followed by TLC), the solvent was evaporated and the residue was purified by chromatography on alumina using CH_2Cl_2 with a gradient of MeOH.

Ligand 5

This ligand was prepared according to the general procedure, starting from a solution of **3** (110 mg, 0.258 mmol) in THF (10 mL), 4'-ethynyl-2,2':6',2''-terpyridine (80 mg, 0.310 mmol), $Pd(PPh_3)_2Cl_2$ (10 mg, 0.014 mmol), CuI (3 mg, 0.016 mmol) and diisopropylamine (3 mL). Purification was performed by chromatography on alumina with CH_2Cl_2–MeOH (0% to 4%) as eluent and afforded 60 mg of **5** (42%); mp 224–225 °C; $[\alpha]_D$ + 41 (5 g/L in CH_2Cl_2).

^{1}H NMR ($CDCl_3$): δ = 3.37 (m, CH_2, 2 H), 3.79 (s, OCH_3, 3 H), 5.12 (m, CH, 1 H), 6.72 (d, $^3J_{H-H}$ = 7.8 Hz, 1 H), 7.11 (d, $^3J_{H-H}$ = 8.4 Hz, 1 H), 7.41 (m, 8 H), 7.74 (dd, $^3J_{H-H}$ = 8.0 Hz, $^4J_{H-H}$ = 1.8 Hz, 2 H), 7.86 (td, $^3J_{H-H}$ = 8.0 Hz, $^4J_{H-H}$ = 1.8 Hz, 2 H), 8.62 (dd, $^3J_{H-H}$ = 8.0 Hz, $^4J_{H-H}$ = 0.7 Hz, 2 H), 8.73 (m, 2 H), 8.83 (m, 2 H).

FT-IR (KBr): ν = 3261 (m), 3057 (m), 2951 (m), 2923 (m), 2854 (m), 1737 (s), 1644 (s), 1608 (s), 1581 (s), 1540 (s), 1466 (s), 1438 (m), 1400 (s), 1347 (w), 1262 (m), 1229 (m), 1121 cm^{-1} (w).

UV-Vis (MeCN): λ_{max} (ε, M^{-1} cm^{-1}) = 286 (28,200), 317 nm (27,900).

MS (FAB$^+$): *m/z* (nature of peak, relative intensity) = 555 ([M + H]$^+$, 100), 496 ([M –CO_2CH_3 + H]$^+$, 20).

Anal. Calcd for $C_{34}H_{26}N_4O_4$ (554.6): C, 73.63; H, 4.73; N, 10.10. Found: C, 73.43; H, 4.42; N, 9.72.

Ligand 6

This ligand was prepared according to the general procedure, starting from a solution of **3** (90 mg, 0.212 mmol) in THF (7 mL), 5-ethynyl-2,2'-bipyridine (46 mg, 0.255 mmol), $Pd(PPh_3)_2Cl_2$ (9 mg, 0.012 mmol), CuI (2.3 mg, 0.012 mmol) and diisopropylamine (1.5 mL). Purification was performed by chromatography on alumina with CH_2Cl_2–MeOH (0% to 3%) as eluent to afford 58 mg of **6** (57%); mp 218–219 °C; $[\alpha]_D$ + 37 (*c* = 5 g/L in CH_2Cl_2).

^{1}H NMR ($CDCl_3$): δ = 3.38 (m, CH_2, 2 H), 3.79 (s, OCH_3, 3 H), 5.12 (m, CH, 1 H), 6.61 (d, $^3J_{H-H}$ = 7.3 Hz, 1 H), 7.08 (m, 3 H), 7.47 (m, 4 H), 7.80 (m, 4 H), 8.22 (dd, $^3J_{H-H}$ = 8.5 Hz, $^4J_{H-H}$ = 2.2 Hz, 1 H), 8.47 (td, $^3J_{H-H}$ = 8.5 Hz, $^4J_{H-H}$ = 2.2 Hz, 2 H), 8.71 (d, $^3J_{H-H}$ = 8.4 Hz, 1 H), 9.15 (m, 1 H).

FT-IR (KBr): ν = 3280 (s), 3047 (s), 2947 (s), 2915 (s), 2365 (w), 1748 (s), 1649 (s), 1579 (m), 1536 (s), 1459 (m), 1434 (m), 1260 (m), 1230 (s), 1009 (m), 795 cm^{-1} (m).

UV-Vis (MeCN): λ_{max} (ε, M^{-1} cm^{-1}) = 336 nm (22,700).

MS (FAB$^+$): *m/z* (nature of peak, relative intensity) = 478 ([M + H]$^+$, 100), 419 ([M – CO_2CH_3 + H]$^+$, 50).

Anal. Calcd for $C_{29}H_{23}N_3O_4$ (477.5): C, 72.94; H, 4.85; N, 8.80. Found: C, 72.62; H, 4.59; N, 8.65.

Ligand 7

This ligand was prepared according to the general procedure, starting from a solution of **4** (100 mg, 0.189 mmol) in THF (8 mL), 4'-ethynyl-2,2':6',2''-terpyridine (58 mg, 0.227 mmol), $Pd(PPh_3)_2Cl_2$ (8 mg, 0.011 mmol), CuI (2 mg, 0.011 mmol) and diisopropylamine (2 mL). Purification was performed by chromatography on alumina with CH_2Cl_2–MeOH (0% to 10%) as eluent to give 61 mg of **7** (49%); mp 232–233 °C; $[\alpha]_D$ + 49 (*c* = 5 g/L in CH_2Cl_2).

^{1}H NMR ($CDCl_3$): δ = 3.23 (m, CH_2, 2 H), 3.82 (s, OCH_3, 3 H), 5.11 (m, CH, 1 H), 6.64 (d, $^3J_{H-H}$ = 6.7 Hz, 1 H), 6.92 (d, $^3J_{H-H}$ = 8.3 Hz, 1 H), 7.11 (d, $^3J_{H-H}$ = 8.5 Hz, 1 H), 7.23 (d, $^4J_{H-H}$ = 2.0 Hz, 1 H), 7.41 (m, 10 H), 7.78 (dd, $^3J_{H-H}$ = 7.8 Hz, $^4J_{H-H}$ = 1.7 Hz, 2 H), 7.87 (td, $^3J_{H-H}$ = 7.8 Hz, $^4J_{H-H}$ = 1.7 Hz, 2 H), 8.53 (s, 2 H), 8.60 (d, $^3J_{H-H}$ = 7.8 Hz, 2 H), 8.73 (m, 2 H).

FT-IR (KBr): ν = 3272 (m), 3058 (w), 2954 (m), 2923 (s), 2851 (m), 2211 (w), 1739 (s), 1637 (m), 1576 (s), 1488 (m), 1465 (s), 1391 (s), 1262 (s), 1215, (m), 1177 (m), 891 (w), 792 cm^{-1} (s).

UV-Vis (MeCN): λ_{max} (ε, M^{-1} cm^{-1}) = 288 (55,900), 311 nm (37,400).

MS (FAB$^+$): *m/z* (nature of peak, relative intensity) = 659 ([M + H]$^+$, 100), 600 ([M – CO_2CH_3 + H]$^+$, 30), 495 ([M – CO_2CH_3 – PhCO + H]$^+$, 10).

Anal. Calcd for $C_{41}H_{30}N_4O_5$ (658.7): C, 74.76; H, 4.59; N, 8.51. Found: C, 74.63; H, 4.42; N, 8.39.

Ruthenium Complexes 8–10; General Procedures

Experimental Condition 1: A stirred solution of Ru(terpy)(DMSO)Cl_2 (1 equiv) and $AgBF_4$ (2 equiv) in argon degassed MeOH was heated at 80 °C for 8 h. After cooling to r.t., the deep-red solution was filtered over cotton-wool and transferred via cannula to a suspension of the terpy-ligands (1 equiv) in MeOH (3 mL) and the solution was heated at 80 °C for 2 d. After complete consumption of the starting material, a solution of KPF_6 (5 equiv) in H_2O (10 mL) was added, the organic solvent was than removed under vacuum and the precipitate was purified by chromatography on alumina eluting with CH_2Cl_2 using a gradient of MeOH (0% to 5%). The pure red-orange compounds were obtained by recrystallization from CH_2Cl_2–hexane.

Experimental Condition 2: A stirred solution of $Ru(bpy)_2Cl_2 \cdot 2H_2O$ (1 equiv) in MeOH and the bipy ligand was heated at 80 °C for 16 h. The pure complex was obtained as described above for compound **1**.

Ruthenium Complex 8

Prepared according to experimental conditions 1, starting from Ru(terpy)(DMSO)Cl_2 (35 mg, 0.07 mmol), $AgBF_4$ (28 mg, 0.14

mmol), of **5** (0.040 g, 0.07 mmol) and MeOH (20 mL) to give 59 mg of **8** (69%).

^{1}H NMR (acetone-d_6): δ = 3.42 (m, CH_2, 2 H), 3.75 (s, OCH_3, 3 H), 5.03 (m, CH, 1 H), 7.29– 7.58 (m, 8 H), 7.68– 7.90 (m, 8 H), 8.04–8.19 (m, 6 H), 8.60 (t, $^3J_{H–H}$ = 8.2 Hz, 1 H), 8.83 (d, $^3J_{H-H}$ = 7.5 Hz, 2 H), 9.07 (m, 4 H), 9.52 (s, 2 H).

FT-IR (KBr) 3070 (m), 2958 (w), 1738 (s), 1652 (s), 1613 (s), 1580 (m), 1541 (s), 1486 (m), 1464 (m), 1450 (s), 1431 (s), 1401 (m), 1389 (s), 1357 (m), 1287 (m), 1267 (m), 1246 (m), 1205 (m), 1135 cm^{-1} (w).

UV-Vis (MeCN): λ_{max} (ε, M^{-1} cm^{-1}) = 272 (40,200), 308 (63,600), 492 nm (28,800).

MS (FAB^+): *m*/*z* (nature of peak, relative intensity) = 1033 ([M – PF_6]$^+$, 16), 889 ([M – 2 PF_6 + H]$^+$, 100), 696 ([M – CH(NH-COPh)(CO_2CH_3) – 2 PF_6]$^+$, 50).

Anal. Calcd for $C_{49}H_{37}F_{12}N_7O_4P_2Ru$ (1177.9): C, 49.92; H, 3.16; N, 8.32. Found: C, 49.74; H, 3.15; N, 8.00.

Ruthenium Complex 9

Prepared according to experimental condition 1, starting from Ru(terpy)(DMSO)Cl_2 (18 mg, 0.04 mmol), $AgBF_4$ (15 mg, 0.08 mmol), **7** (25 mg, 0.04 mmol) and MeOH (15 mL) to give 28 mg of **9** (58%).

^{1}H NMR (acetone-d_6): δ = 3.43 (m, CH_2, 2 H), 3.74 (s, OCH_3, 3 H), 5.02 (m, CH, 1 H), 7.28– 7.56 (m, 10 H), 7.67– 7.90 (m, 10 H), 8.03– 8.22 (m, 6 H), 8.59 (t, $^3J_{H-H}$ = 8.1 Hz, 1 H), 8.83 (d, $^3J_{H-H}$ = 8.3 Hz, 2 H), 9.07 (t, $^3J_{H-H}$ = 8.1 Hz, 4 H), 9.53 (s, 2 H).

FT-IR (KBr): ν = 2955 (m), 2924 (s), 2854 (m), 1738 (s), 1652 (m), 1601 (s), 1579 (m), 1533 (s), 1484 (m), 1449 (s), 1385 (s), 1287 (m), 1266 (m), 1247 (s), 1196 (m), 1020 (w), 842 cm^{-1} (s).

UV-Vis (MeCN): λ_{max} (ε, M^{-1} cm^{-1}) = 272 (39,000), 308 (57,200), 492 nm (24,400).

MS (FAB^+): *m*/*z* (nature of peak, relative intensity) = 1138 ([M – PF_6]$^+$, 100), 1079 ([M – CO_2CH_3 – PF_6]$^+$, 60), 993 ([M – 2PF_6]$^+$, 10), 974 ([M – CO_2CH_3 – PhCO – PF_6]$^+$, 30).

Anal. Calcd for $C_{56}H_{41}F_{12}N_7P_2O_5Ru{\cdot}CH_3CN$ (1324.1): C, 52.61; H, 3.35; N, 8.46. Found: C, 52.74; H, 3.49; N, 8.63.

Ruthenium Complex 10

Prepared according to experimental conditions 2, starting from $Ru(bpy)_2Cl_2{\cdot}2H_2O$ (22 mg (0.04 mmol)), **6** (20 mg, 0.04 mmol) and MeOH (20 mL), to give 26 mg of **10** (58%).

^{1}H NMR (acetone-d_6): δ = 3.34 (m, CH_2, 2 H), 3.69 (s, OCH_3, 3 H), 4.95 (m, CH, 1 H), 7.38– 7.95 (m, 14 H), 8.07– 8.39 (m, 12 H), 8.58 (t, $^3J_{H-H}$ = 7.5 Hz, 1 H), 8.84 (m, 6 H).

FT-IR (KBr): ν = 2951 (w), 1741 (s), 1648 (s), 1602 (s), 1529 (m), 1444 (s), 1441 (s), 1245 (m), 1216 (m), 1035 (w), 843 cm^{-1} (s).

UV-Vis (MeCN): λ_{max} (ε, M^{-1} cm^{-1}) = 286 (64,000), 333 (22,200), 365 (33,000), 454 nm (10,900).

MS (FAB^+): *m*/*z* (nature of peak, relative intensity) = 1035 ([M – PF_6 – H]$^+$, 35), 930 ([M – PhCO – PF_6]$^+$, 100), 890 ([M – 2PF_6 – H]$^+$, 14), 831 ([M – CO_2CH_3 – 2PF_6 – H]$^+$, 6).

Anal. Calcd for $C_{49}H_{39}N_7O_4RuP_2F_{12}$ (1180.9): C, 49.84; H, 3.33; N, 8.30. Found: C, 49.71; H, 3.12; N, 8.19.

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