Conversion of a new chiral reagent Δ-[Ru(bpy)$_2$(dmso)Cl]PF$_6$ to Δ-[Ru(bpy)$_2$(dmbpy)]PF$_6$Cl with 96.8% retention of chirality (dmbpy = 4,4′-dimethyl-2,2′-bipyridine)

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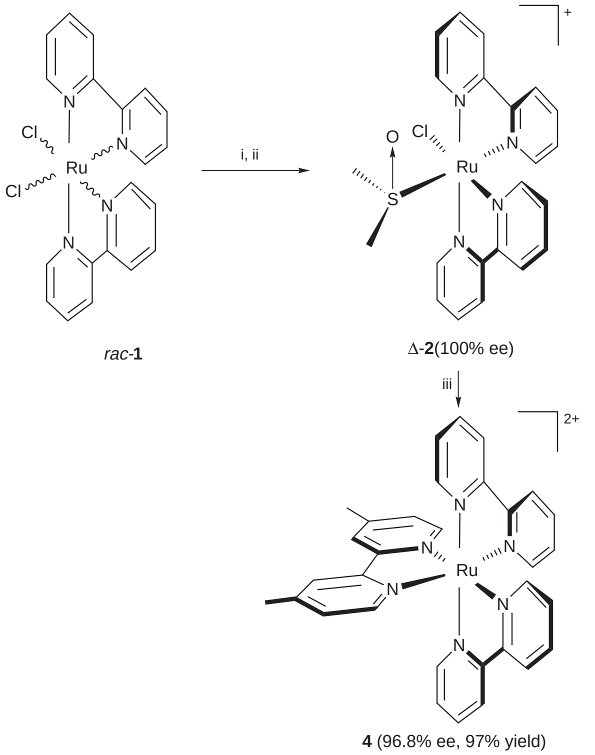
The new chiral ruthenium bis(bpy) sulfoxide reagent, Δ-*cis*-[Ru(bpy)$_2$(dmso)Cl]PF$_6$ (100% ee following HPLC resolution) is used to prepare Δ-[Ru(bpy)$_2$(dmbpy)][PF$_6$]Cl in excellent yield (97%) with almost complete retention of absolute configuration (96.8%), as confirmed by X-ray crystallographic studies on a single enantiomer of [Ru(bpy)$_2$(dmbpy)][PF$_6$]Cl (obtained without resolution or chromatographic methods) and by analysis of the optical properties of both the precursor and product.

Optically pure octahedral ruthenium complexes have been known for many years, and are important synthetic targets.[1] Many synthetic procedures are known for their preparation but almost all of these processes rely on a resolution technique at the final stage in the preparation.[2,3] Although a diastereoselective synthesis using the so-called chiragen ligands has been reported,[4–6] the absence of a *general* asymmetric synthesis of ruthenium tris(bpy) complexes necessitates a compromise position. The preparation, and resolution of an enantiomerically pure precursor, which is stable enough to be handled, yet sufficiently reactive to allow a quantitative conversion to the desired complex, ideally with no loss of optical activity during this transformation represents such a compromise. The envisioned precursor should also comprise simple materials, that can be easily combined, then readily separated. Such methodology has been reported previously by Hua and von Zelewsky[7,8] who have developed [Ru(bpy)$_2$(py)$_2$]$^{2+}$, and by Keene and coworkers,[1,3,9] who have developed [Ru(bpy)$_2$(CO)$_2$]$^{2+}$. Both of these complexes have been resolved and subsequently applied in the synthesis of enantiomerically pure ruthenium tris(bpy) complexes in a stereoselective fashion. We have sought to add to this highly interesting work by searching for a new ruthenium complex which bears the aforementioned properties, since the availability of the widest possible range of chiral reagents permits the synthetic inorganic chemist to carefully tune the reaction conditions according to the type of product that is required. Herein we wish to report that such a precursor has been realized during the course of our research into the photochemical properties of octahedral ruthenium complexes.[10] Racemic *cis*-[Ru(bpy)$_2$Cl$_2$] **1** is converted to *cis*-[Ru(bpy)$_2$(Me$_2$SO)Cl]Cl **2** when it is heated at 85 °C in dry, deaerated Me$_2$SO for 5 h. After evaporation of the solvent, the racemic product is treated with ether and hot acetone to remove excess Me$_2$SO. The Δ- and Λ-enantiomers of **2** can be readily and completely separated by HPLC,† using a chiral stationary phase during which a counter ion exchange of Cl$^-$ to PF$_6^-$ occurs, and the enantiomers are found not to interconvert, even upon heating in Me$_2$SO for 2 h. NMR techniques allow us to confirm the sulfoxide product,‡ and IR shows that the sulfoxide is S-, not O-bonded, as demonstrated by the S-ligated sulfoxide stretching frequency at 1120 cm^{-1}.[11] It is important to note that **2**·Cl$^-$ is soluble in polar/protic solvents [much more so than Ru(bpy)$_2$Cl$_2$], but is slightly unstable upon prolonged exposure to light, slowly decomposing over several hours if left uncovered. However, the light sensitivity is not so high that completely dark conditions are required, and short exposure times do not result in any noticeable photodegradation.

Stereochemistry at the metal center is almost completely retained when resolved Δ-**2**·PF$_6$ (ee = 100%) is heated to 75 °C for 2 h with 4,4′-dimethyl-2,2′-bipyridine **3** (dmbpy) in a mixture of ethanol and acetic acid (8 : 1), affording Δ-[Ru(bpy)$_2$(dmbpy)][PF$_6$]Cl **4** in 97% yield, with an ee of 96.8% (Scheme 1). Thus, the dmso precursor reacts with near quantitative conversion, and shows almost complete stereoretention, rendering it suitable as a chiral reagent in the stereocontrolled synthesis of ruthenium tris(bpy) complexes.



Scheme 1 *Reagents and conditions*: i, DMSO, 85 °C, 5 h; ii, HPLC resolution; iii, dmbpy, EtOH–AcOH, 75 °C, 2 h.

The circular dichroism (CD) and UV–VIS spectra of both Δ-**2** and **4** are shown in Fig. 1. The main features of the CD spectra are the ligand centered bands at *ca*. 275 nm, and the MLCT bands at *ca*. 450 nm. Assignments are based on previously reported data for **1** and related ruthenium complexes.[12–14] The spectra of Δ-**2** and **4** are supported by strong, independent structural data. It should be noted that because the synthesis was stereoretentive, *no resolution procedure* was applied either in the synthesis or in the purification. The material obtained was

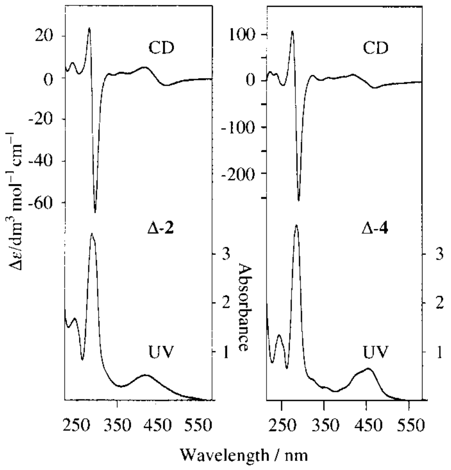


Fig. 1 CD and UV–VIS spectra of Δ-**2** and Δ-**4**.

subsequently shown to be enantiomerically pure by CD spectroscopy and HPLC. A crystal of **4** was grown from this sample using an EtOH–MeCN mixed solvent and subjected to X-ray analysis. The chirality was established as Δ using the method of Bijvoet[15] as indicated by the Flack parameter and *R* factor tests. The structure obtained is shown in Fig. 2.§ This study is therefore of high interest, as there are very few examples of the X-ray structures of enantiomerically pure ruthenium polypyridyl complexes in the literature which are accompanied by CD spectra.[3] The absolute configuration at the metal centre was also confirmed by comparison of the CD spectra and X-ray crystal structure of **4** with the previously recorded X-ray crystal structure of Λ-[Ru(dmbpy)$_2${4,4′-bis[(*R*)-(+)-α-phenylethylamido]-2,2′-bipyridine}[PF$_6$]$_2$ which has known stereocentres, and was therefore solved with complete certainty.[16] In **4**, the metal is in an octahedral environment with Ru–N distances ranging from 2.055(5) to 2.077(5) Å.

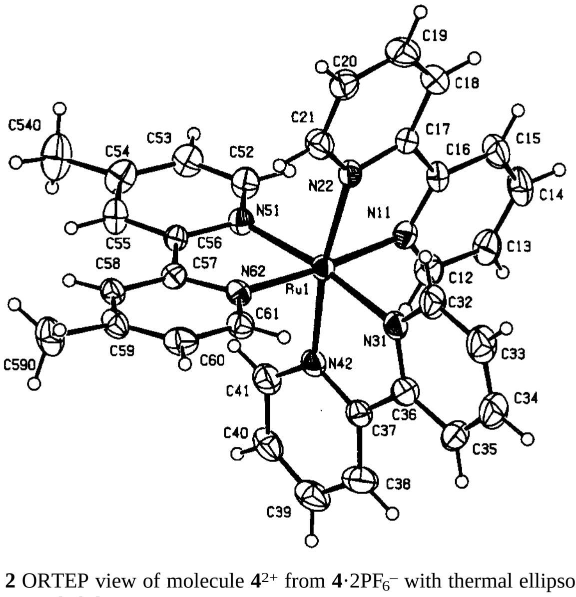


Fig. 2 ORTEP view of molecule **4**$^{2+}$ from **4**$\cdot 2PF_6^-$ with thermal ellipsoids at 30% probability.

In summary, *cis*-[Ru(bpy)$_2$(Me$_2$SO)Cl]PF$_6$ **2** can be prepared using very simple experimental techniques. This ruthenium bis(bpy) sulfoxide is stable (in the absence of strong light), and can be readily resolved to give the new, enantiomerically pure chiral reagent. This can be used for the synthesis of ruthenium tris(bpy) complexes with almost complete stereoretention at the metal centre, as exemplified by the preparation of **4**, which has been confirmed by CD and X-ray methods. To date, only two other complexes have been reported that can be used in this manner, and these have received a good deal of attention, demonstrating the importance of this type of reagent.[1,3,7–9] The synthesis outlined above is both simple and reliable, affording a product with a high enantiomeric excess, in near quantitative yield. This easy to handle chiral sulfoxide reagent is already beginning to prove invaluable in the synthesis of complicated, enantiomerically enriched/pure ruthenium tris(bpy) complexes (for example, the synthesis of a novel tetrakis[ruthenium tris(bipyridine)]calix[6]arene derivative with good diastereomeric purity[17]), and its use in this role will be the subject of future reports from our laboratories.

Notes and references

† HPLC was carried out using a CHIRACEL OD-R column (Diacel Chemical Industries Ltd.) (20 mm diameter × 250 mm length) with aqueous NaPF$_6$ (1 mol dm^{-3}) as the mobile phase. For a flow rate of 3 ml min^{-1}, retention times of 16.90 min for Δ-**2**, 34.6 min for Δ-**4** and 29.6 min for Λ-**4** were observed.

‡ *Selected data* for Δ-**2**: ^{1}H NMR (CD_3CN) δ 10.12 (d, *J* 5.6, 1H, Ha-6), 9.63 (dd, *J* 5.6 Hz, 1.3 Hz, 1H, Hd-6), 8.68 (d, *J* 8.4 Hz, 1H, Hd-3), 8.53 (m, 2H, Ha,b-3), 8.44 (d, *J* 8.4 Hz, 1H, Hc-3), 8.27 (t, *J* 7.6 Hz, 1H, Hd-4), 8.12 (t, *J* 7.6 Hz, 1H, Ha-4), 7.93 (m, 2H, Hb,c-4), 7.86 (d, *J* 5.2 Hz, 1H, Hc-6), 7.84 (t, *J* 8.0 Hz, 1H, Hd-5), 7.73 (t, *J* 8.0 Hz, 1H, Ha-5), 7.24 (m, 2H, Hb,c-5), 7.20 (d, *J* 4.8 Hz, 1H, Hb-6), 3.13 (s, 3H, CH$_3$), 2.06 (s, 3H, CH$_3$). Anal. Calc. for $C_{22}H_{22}Cl_2N_4ORuS\cdot H_2O$ (M = 580.0) C, 45.51; H, 4.17; N, 9.65. Found: C, 44.98; H, 3.96; N, 9.41%.

§ $C_{34}H_{31}F_{12}N_7P_2Ru$, M = 928.67, orthorhombic, space group $P2_12_12_1$, a = 13.731(11), b = 20.496(9), c = 13.521(8) Å, V = 3805 Å^3, Z = 4, μ = 0.591 mm^{-1}, D_c = 1.621 Mg m^{-3}; 8740 independent reflections were measured on a Rigaku 4-circle diffractometer. Refinement on F^2 *via* SHELXL (G. M. Sheldrick, 1997, program for crystal structure refinement) gave an R of 0.0519 for 6197 reflections with $I > 2\sigma(I)$. Flack parameter −0.07(5). Reverse coordinates gave R = 0.0542. CCDC 182/1152. See http://www.rsc.org/suppdata/cc/1999/403/ for crystallographic files in .cif format.

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