

Catalytic kinetic spectrophotometric determination of palladium(II) and its application to the determination of traces of propylthiouracil

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The catalytic-kinetic method has been proposed for the determination of palladium(II) based on its catalytic effect on the reaction of crystal violet with hypophosphite. The reaction has been monitored spectrophotometrically at 590 nm over the range 0.071-2.850 ppm of Pd(II). The influence of reaction variables and the effect of interfering ions have been studied. The limit of detection and relative standard deviation are 0.071 ppm and 2.76%, respectively. The developed method has been applied to the determination of Pd(II) in river water and Pd-C catalyst. The proposed method has also been applied for the determination of propylthiouracil in pharmaceutical samples based on its inhibitory effect on the palladium(II)-catalyzed reaction between crystal violet and hypophosphite ions. The decrease in absorbance of crystal violet at 590 nm is proportional to 1.7-248.0 ppb of PTU. The limit of detection and RSD are 1.7 ppb and 2.53%, respectively.

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Propylthiouracil (PTU, 6-propyl-2-thiouracil) belongs to a class of antithyroid drugs called thionamides or thioureylenes for the non-destructive therapy of hyperthyroidism. PTU is potent inhibitor of thyroidperoxidase enzymes responsible for the iodination of tyrosine residues of thyroglobulin and the coupling of iodotyrosine residues to form iodothyronines. In addition, PTU is the drug of choice in the treatment of thyroid storm because of its ability to inhibit 5'-deiodinase, which is responsible for the peripheral deiodination of T₄ to T₃¹.

This compound has been determined by titration², polarographic³, potentiometric⁴, conductometric⁵, and spectrophotometric⁶ methods. The concentration of

PTU in biological fluid has been measured by HPLC^{7,8}. Most of the proposed methods are laborious, costly and require complicated and expensive instruments or are time consuming, or provided high detection limits. Therefore, it was thought fruitful to develop a sensitive, simple and reliable method for the determination of PTU.

Palladium is an important element in metallurgy owing to its corrosion resistance nature and alloying ability^{9,10}. Even when sensitive techniques are employed such as NAA and ICP-MS, it is necessary to separate and concentrate Pd(II) before analysis¹¹. Among different methods of analysis like NAA, ICP-MS, FAAS and spectrophotometry^{12,13}, the latter is widely used method.

In the first part of the present work, a catalytic-kinetic method for the determination of Pd(II) based on the reduction of crystal violet by hypophosphite in the presence of trace amounts of palladium(II) is proposed. The developed method has been applied with good results for the determination of Pd(II) in Pd-C catalyst and river water samples. Furthermore, in the second part of this work, a simple, sensitive and rapid method has been developed for the determination of PTU based on its inhibitory effect on the Pd(II) catalyzed reaction of crystal violet with hypophosphite. The reaction has been monitored spectrophotometrically at the maximum wavelength of crystal violet (590 nm), while measuring the change in the absorbance with time.

Experimental

All chemicals were of analytical-reagent grade and the solutions were prepared with doubly distilled water. Working solutions with lower concentrations were prepared by appropriate dilution of their respective stock solutions. All concentrations described here are the initial concentrations in the reaction mixture at time zero after mixing. Each kinetic result is the average of three determinations.

Crystal violet stock solution (9.78×10^{-5} M) was prepared by dissolving 0.0040 g of dye-stuff (Merck) in water and diluting to 100 ml in a dark calibrated volumetric flask with doubly distilled water.

Britton-Robinson buffer was prepared by mixing suitable amounts of H₃BO₃, CH₃COOH and H₃PO₄

and adding required amounts of NaOH in a 100 ml volumetric flask.

Palladium(II) stock solution (1000 ppm) was prepared by dissolving 0.167 g of (PdCl₂, Merck) in 2.0 ml of 3.0 M HCl and diluting to 100 ml in a volumetric flask with water, and standardized by dimethylglyoxime¹⁴.

Hypophosphite solution (1.0 M) was prepared weekly by dissolving 10.599 g of sodium hypophosphite salt (Merck) in a dark volumetric flask and diluting to 100 ml with water.

Stock solution of PTU (340 ppm) was prepared by dissolving 0.0340 g (C₇H₁₀N₂C₂S, Merck) in water and diluting to 100 ml in a dark volumetric flask. An aliquot of this solution (5.0 ml) was diluted to 100 ml with water and used as working solution. This solution was standardized¹⁵.

The absorption spectra were recorded on a Cecil 9000 UV-Vis spectrophotometer and absorption-time (*A-t*) profiles were recorded on a computerized Metrohm 662 probe type photometer. The Metrohm photometer was connected to a Pentium III personal computer using a 12 bit A/D card (model 1201 Bitpardaz Co., Iran) and the appropriate software was written in Quick Basic in our laboratory. A magnetic stirrer (model ZMS, ZAG Chemei Co., Iran) was used for mixing of reagents. The *pH* measurements were made with a 692 Metrohm *pH* meter using a combined glass electrode. The temperature was kept constant (25 ± 0.5 °C) by a thermostat bath (HAAKE D1). All the solutions were previously brought to this temperature. The temperature was maintained constant in the reaction cell by circulating water around the cell during the experiment. These developed methods are based on the variable time method.

Procedure for the determination of Pd (II)

In the reaction cell, 3.0 ml (9.78 × 10⁻⁵ M) of crystal violet solution was added to 1.0 ml of 1.0 M hypophosphite and 1.0 ml of Britton-Robinson buffer solution (*pH* = 5.7) and diluted to 7.0 ml with doubly distilled water. Probe of the photometer was inserted in the cell and the change in absorbance of solution was monitored. A magnetic stirrer was used to mix the solution within the cell. Then, 50.0 µl of palladium(II) solution was added to the cell and the absorbance versus time data were collected by the computer. In order to remove any traces of Pd(II) adsorbed on the cell walls, washing the cell with 6.0 M HNO₃ after each run is recommended.

Procedure for the determination of PTU

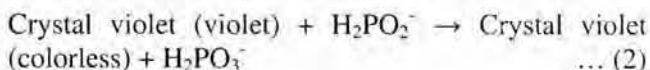
After a suitable aliquot of PTU solution was transferred into a 10 ml volumetric flask, 1.0 ml (4.30 × 10⁻⁵ M) of crystal violet, 1.5 ml of 1.0 M hypophosphite and 1.0 ml of Britton-Robinson buffer solution were added and diluted to 10.0 ml with doubly distilled water. Then 70.0 µl of 20.0 ppm Pd(II) solution was added to the reaction cell and the absorbance versus time data were collected. This method is based on the inhibitory effect of PTU on the reaction of crystal violet with hypophosphite in the presence of Pd(II). The percent of inhibition (%) was calculated as:

$$(\%) = 100 [(dA/dt)_{cat.} - (dA/dt)_{in.}] / (dA/dt)_{cat.} \quad \dots (1)$$

Results and discussion

Determination of Pd(II)

The reduction reaction of crystal violet with hypophosphite in the presence of Pd (II) is as follows:



Initially, hypophosphite reduces Pd(II) to Pd(0) with hypophosphite decomposing and produces hydrogen that reduces the crystal violet. It is well known that when hydrogen is adsorbed on Pd metal it becomes activated¹⁶. The absorbance of dye-stuff at 590 nm decreases with progress of the reaction.

The effect of *pH* on the rate of reaction was studied by addition of HCl or NaOH solution to the test solution. It was observed that *pH* of the reaction medium affects the rate of catalyzed reaction and the maximum rate was achieved over the *pH* range 5.0-6.0. The length of the induction time increases and the rate of reaction gradually decreases as the *pH* increases above 6.0 or decreases below 5.0. The effect of low *pH* values may result from excessive protonation of the crystal violet. At high *pH* values, Pd(II) hydrolyzed and its catalytic activity decreases. Hence, subsequent studies were carried out at *pH* = 5.7.

The effect of amount of Britton-Robinson buffer on the rate of catalyzed reaction was investigated and the results show that addition of small amounts of buffer has no considerable effect on the reaction rate. A further increase in the buffer volume decreases the reaction rate. Thus, 1.0 ml Britton-Robinson buffer was selected for further studies.

The effect of crystal violet concentration on the rate of reaction was studied in the range 1.02 × 10⁻⁶ -

$6.78 \times 10^{-6} M$. The rate of reaction remains constant in the concentration range of $3.03 \times 10^{-6} - 4.11 \times 10^{-6} M$. Further addition of dye reduces the rate of reaction. Therefore, optimum concentration of crystal violet was chosen as $3.7 \times 10^{-6} M$ in final solution.

At optimum concentration of dye, the effect of hypophosphite concentration on the rate of catalyzed reaction was studied and optimum concentration of hypophosphite in the final solution obtained was $0.314 M$.

The effect of ionic strength on the reaction rate of catalyzed reaction was also studied. The ionic strength of the solution was varied from $0.0-0.54 M$ using KNO_3 solution. The rate of reaction was found to remain constant at its maximum level when the KNO_3 concentration was in the range $0.0-0.28 M$ and decreased gradually with concentration greater than $0.28 M$.

The influence of reaction temperature was studied in the range $15-45^\circ C$ at optimum conditions. Significant increase in the rate of reaction was seen. For sake of convenience, temperature of $25^\circ C$ was selected for further study.

Under optimum conditions described above, a linear calibration graph was obtained in the concentration range of $0.071-2.857$ ppm with a correlation coefficient of 0.9976 and a regression equation of $1/\Delta t = 0.0054 + 0.033 C$, where t and C indicate the time (s) elapsed for the absorbance to decrease from its initial value to a reference point (5% of initial absorbance) and Pd(II) concentration (ppm), respectively. The experimental detection limit was 0.071 ppm. The relative standard deviation of 7 replicate measurements was 2.76% for a 1.14 ppm Pd(II) solution.

Determination of PTU

Organic compounds containing sulfur can react with Pd(II) and produce soluble complexes¹⁷. Therefore, PTU decreases the catalytic effect of Pd(II) on the reaction of the crystal violet-hypophosphite system. The reaction rate of the catalyzed reaction decreased with increasing amounts of PTU and time required for the absorbance to decrease to a predetermined value increased. The reaction was monitored spectrophotometrically by measuring the time required for the absorbance of the crystal violet to decrease by 0.05 (at $\lambda_{\max} = 590$ nm) by variable time method.

The effect of pH on the inhibited reaction was studied by adding 1.0 ml Britton-Robinson buffer of

pH= $3.0-7.0$. The study showed the maximum %I to be in the range of $5.0-6.0$. Thus pH= 5.5 was selected for further studies.

Study on the effect of hypophosphite concentration showed that the %I increases with increasing concentration of hypophosphite up to $0.24 M$, above which it decreases.

The influence of crystal violet concentration was studied in the range of $1.72 \times 10^{-6} - 5.16 \times 10^{-6} M$. A concentration of $4.3 \times 10^{-6} M$, at which the inhibitory effect of PTU was maximum, was selected as optimum dye concentration.

The effect of concentration of Pd(II) on the reaction rate was studied in the range of $0.10-0.225$ ppm Pd(II). A concentration of 0.175 ppm of Pd(II) was found the most suitable concentration.

The influence of ionic strength was studied by addition of KNO_3 ($2.0M$) solution in the concentration range $0.12-0.41 M$. The percentage of inhibition increased with increasing of KNO_3 concentration up to $0.32 M$, above which the %I remained constant. Thus, $0.32 M$ KNO_3 was chosen for further experiments.

The effect of temperature, under the selected experimental conditions was studied in the range $15-45^\circ C$. Percentage of inhibition decreased on increasing the temperature. A temperature of $25^\circ C$ was chosen for further experiments because of convenience.

Under optimum conditions described above ([hypophosphite]= $0.24 M$; [dye]= $4.3 \times 10^{-6} M$; [Pd]= 0.175 ppm; pH= 5.5 ; buffer volume= 1.0 ml; $T= 25^\circ C$; $\lambda_{\max}= 590$ nm), a linear calibration graph was obtained in the concentration range of $1.71-248.12$ ppb of PTU with a correlation coefficient of 0.9980 and a regression equation of $1/\Delta t = 0.0529 - 0.0002C$, where t and C indicate the time elapsed (s) for the absorbance

Table I—The effect of diverse ions on the determination of 1.14 ppm Pd (II)

Ion added	Tolerated ratio of foreign ion to Pd (II)
$Na^+, K^+, Ca^{2+}, Mg^{2+}, NO_3^-$	1000
$F^-, Cl^-, Zn^{2+}, Cr^{3+}$	500
$Fe^{2+}, Co^{2+}, Ba^{2+}$	200
$CO_3^{2-}, S_2O_3^{2-}, HPO_4^{2-}$	100
$I^-, Br^-, IO_3^-, C_2O_4^{2-}$	50
$S^{2-}, Cr_2O_7^{2-}, ClO_3^-$	20
Ni^{2+}	10
SCN^-, NO_2^-, Hg^{2+}	Interfere
Fe ³⁺ , Th ⁴⁺ , Sn ²⁺ , Cd ²⁺ , Ag ⁺ , Cu ²⁺ , La ³⁺ and Pb ²⁺ were precipitated at the desired pH and after filtration did not interfere.	

Table 2—Determination of Pd (II) in real samples and PTU in tablet

Sample	Proposed method (ppm)	AAS method (ppm)	RSD (%)
Pd-C catalyst1	0.125	0.128	2.4
Pd-C catalyst2	0.546	0.555	2.0
River water	1.381	1.364	1.7
Tagh-e-Bostan water	0.341	0.330	2.2
PTU tablet ² (50 mg)	49.1 mg	51.7 mg (ref.15)	2.6

¹ Average of three determinations² Obtained from Iran Hormone Pharmaceutical Company (Tehran, Iran).

to decrease from its initial value to a reference point (5% of initial absorbance) and PTU concentration (ppb), respectively. The experimental detection limit was 1.7 ppb. The relative standard deviation of 8 replicate measurements was 2.53% for an 84.0 ppb PTU solution.

Interference studies

In order to study the effect of various ions on the determination of Pd(II), a fixed concentration of palladium (1.14 ppm) was used with varying amounts of foreign ions and the recommended procedure was followed. The results are summarized in Table 1. An error of 5% in the determination of Pd (II) was tolerable.

The effect of commonly used excipients and additives (such as lactose, starch, glucose, saccharose and magnesium stearate) was investigated before the determination of PTU in tablet form. No interference was observed.

Applications

The present method for the determinations of Pd(II) and PTU is sensitive and free from interference of foreign species or additives, and has a good selectivity.

The catalytic kinetic method was applied for the determination of Pd(II) in Pd-C catalyst and river water samples. The solution of catalyst was prepared as described in literature¹⁸. The results are summarized in Table 2.

For the determination of PTU in pharmaceutical preparation, five tablets were weighed and ground to a fine powder. Then, 0.1 g of this powder was weighed accurately, transferred into a 5 ml volumetric flask, dissolved in water and diluted up to the mark. This solution was transferred into a 25 ml separatory funnel and extracted with 5.0 ml CH₂Cl₂. The remaining aqueous phase solution was further extracted with another 5.0 ml of fresh organic solvent. The organic phase was then separated and added to

the previously separated organic phase and mixed in beaker. This solution was kept at room temperature till dryness. The sample was dissolved in water and transferred into a 100 ml volumetric flask (diluted with water). An aliquot (5.0 ml) of this solution was transferred into a 100 ml volumetric flask and diluted up to the mark. An aliquot (25 µl) of this solution was transferred into the reaction cell and concentration of PTU was determined according to the recommended procedure. The result obtained using the proposed method was in good agreement with that obtained by applying the reference method¹⁵ (Table 2).

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