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**Water quality — Spectrometric  
determination of phosphorus using  
ammonium molybdate**

*Qualité de l'eau — Dosage spectrométrique du phosphore en utilisant  
le molybdate d'ammonium*

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## Foreword

ISO (the International Organization for Standardization) is a world-wide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 6878 was prepared by Technical Committee ISO/TC 147, *Water quality*, Subcommittee SC 2, *Physical, chemical, biochemical methods*.

This first edition of ISO 6878 cancels and replaces the first edition of ISO 6878-1:1986, which has been technically revised.

Annexes A, B and C of this International Standard are for information only.

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# Water quality — Spectrometric determination of phosphorus using ammonium molybdate

## 1 Scope

This International Standard specifies the determination of different forms of phosphorus compounds present in the dissolved and undissolved states in various concentrations in ground, surface and waste waters.

In particular, methods are given for the determination of

- orthophosphate (see clause 3);
- orthophosphate after solvent extraction (see clause 4);
- hydrolysable phosphate plus orthophosphate (see clause 5);
- total soluble phosphorus and total phosphorus after decomposition (see clauses 6 and 7).

The methods are applicable to all kinds of water, including seawater and effluents. Phosphorus contents within the range of 0,005 mg/l to 0,8 mg/l may be determined in such samples without dilution.

A solvent extraction procedure allows smaller phosphorus concentrations to be determined with a detection limit of about 0,0005 mg/l .

See annex B for some known interferences. There may be others and it is recommended to verify whether any such exist and take action to remove them.

## 2 Principle

Orthophosphate ions are reacted with an acid solution containing molybdate and antimony ions to form an antimony phosphomolybdate complex.

The complex is reduced with ascorbic acid to form a strongly coloured blue molybdenum complex. The absorbance of this complex is measured to determine the concentration of orthophosphate present.

Polyphosphate and some organophosphorus compounds are determined if converted to molybdate-reactive orthophosphate formed by sulfuric acid hydrolysis.

Many organophosphorus compounds are converted to orthophosphate by mineralization with persulfate. Nitric acid-sulfuric acid mineralization is used if a more vigorous treatment is required.

### 3 Determination of orthophosphate

#### 3.1 Reagents

During the analysis, use only reagents of recognized analytical grade and only distilled water having a phosphate content that is negligible compared with the smallest concentration to be determined in the samples.

For low phosphate contents, double-distilled water from an all-glass apparatus is recommended.

##### 3.1.1 Sulfuric acid, solution, $c(\text{H}_2\text{SO}_4) = 9 \text{ mol/l}$

Add 500 ml  $\pm$  5 ml of water to a 2 l beaker. Cautiously add, with continuous stirring and cooling, 500 ml  $\pm$  5 ml of sulfuric acid,  $\rho = 1,84 \text{ g/ml}$ . Mix well and allow the solution to cool to room temperature.

##### 3.1.2 Sulfuric acid, solution, $c(\text{H}_2\text{SO}_4) = 4,5 \text{ mol/l}$

Add 500 ml  $\pm$  5 ml of water to a 2 l beaker. Cautiously add, with continuous stirring and cooling, 500 ml  $\pm$  5 ml of sulfuric acid (see 3.1.1). Mix well and allow to cool to room temperature.

##### 3.1.3 Sulfuric acid, solution, $c(\text{H}_2\text{SO}_4) = 2 \text{ mol/l}$

Add 300 ml  $\pm$  3 ml of water to a 1 l beaker. Cautiously add 110 ml  $\pm$  2 ml of sulfuric acid solution (see 3.1.1), with continuous stirring and cooling. Dilute to 500 ml  $\pm$  2 ml with water and mix well.

##### 3.1.4 Sodium hydroxide, solution, $c(\text{NaOH}) = 2 \text{ mol/l}$

Dissolve 80 g  $\pm$  1 g of sodium hydroxide pellets in water, cool and dilute to 1 l with water.

##### 3.1.5 Ascorbic acid, solution, $\rho = 100 \text{ g/l}$

Dissolve 10 g  $\pm$  0,5 g of ascorbic acid ( $\text{C}_6\text{H}_8\text{O}_6$ ) in 100 ml  $\pm$  5 ml water.

NOTE The solution is stable for two weeks if stored in an amber glass bottle in a refrigerator and can be used as long as it remains colourless.

##### 3.1.6 Acid molybdate, solution I

Dissolve 13 g  $\pm$  0,5 g of ammonium heptamolybdate tetrahydrate  $[(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}]$  in 100 ml  $\pm$  5 ml of water. Dissolve 0,35 g  $\pm$  0,05 g of antimony potassium tartrate hemihydrate  $[\text{K}(\text{SbO})\text{C}_4\text{H}_4\text{O}_6 \cdot 1/2\text{H}_2\text{O}]$  in 100 ml  $\pm$  5 ml of water.

Add the molybdate solution to 300 ml  $\pm$  5 ml of sulfuric acid (see 3.1.1) with continuous stirring. Add the tartrate solution and mix well.

NOTE The reagent is stable for at least two months if stored in an amber glass bottle.

##### 3.1.7 Acid molybdate, solution II

Add 230 ml  $\pm$  0,5 ml of sulfuric acid (see 3.1.1) to 70 ml  $\pm$  5 ml of water, cool. Dissolve 13 g  $\pm$  0,5 g of ammonium heptamolybdate tetrahydrate  $[(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}]$  in 100 ml  $\pm$  5 ml of water. Add to the acid solution and mix well. Dissolve 0,35 g  $\pm$  0,05 g of antimony potassium tartrate hemihydrate  $[\text{K}(\text{SbO})\text{C}_4\text{H}_4\text{O}_6 \cdot 1/2\text{H}_2\text{O}]$  in 100 ml  $\pm$  5 ml of water. Add to the molybdate-acid solution and mix well.

This reagent is used when the sample is acidified with sulfuric acid (see 3.1.2) (see clauses 5 and 6).

NOTE The reagent is stable for at least two months if stored in an amber glass bottle.

### 3.1.8 Turbidity-colour compensation solution

On a volume/volume basis, mix two parts of sulfuric acid (see 3.1.2) and one part of ascorbic acid (see 3.1.5).

NOTE The reagent is stable for several weeks if stored in an amber glass bottle in a refrigerator.

### 3.1.9 Sodium thiosulfate pentahydrate, solution, $\rho = 12,0$ g/l

Dissolve  $1,20 \text{ g} \pm 0,05 \text{ g}$  of sodium thiosulfate pentahydrate ( $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ ) in  $100 \text{ ml} \pm 5 \text{ ml}$  of water. Add  $0,05 \text{ g} \pm 0,005 \text{ g}$  of anhydrous sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) as preservative.

NOTE The reagent is stable for at least four weeks if stored in an amber glass bottle.

### 3.1.10 Orthophosphate, standard stock solution, $\rho = 50$ mg/l

Dry a few grams of potassium dihydrogen phosphate to constant mass at  $105^\circ\text{C}$ . Dissolve  $0,2197 \text{ g} \pm 0,0002 \text{ g}$  of  $\text{KH}_2\text{PO}_4$  in about  $800 \text{ ml} \pm 10 \text{ ml}$  of water in a  $1000 \text{ ml}$  volumetric flask. Add  $10 \text{ ml} \pm 0,5 \text{ ml}$  of sulfuric acid (see 3.1.1) and make up to the mark with water.

NOTE The solution is stable for at least three months if stored in a well-stoppered glass bottle. Refrigeration to about  $4^\circ\text{C}$  is recommended.

### 3.1.11 Orthophosphate, standard solution, $\rho = 2$ mg/l

Pipette  $20 \text{ ml} \pm 0,01 \text{ ml}$  of orthophosphate standard stock solution (see 3.1.10) into a  $500 \text{ ml}$  volumetric flask. Make up to the mark with water and mix well.

Prepare and use this solution each day it is required.

NOTE 1 ml of this standard solution contains  $2 \mu\text{g P}$ .

### 3.1.12 Hydrochloric acid, $\rho(\text{HCl}) = 1,12$ g/ml

### 3.1.13 Hydrochloric acid, $c(\text{HCl}) = 2$ mol/l

Add  $200 \text{ ml} \pm 10 \text{ ml}$  of hydrochloric acid (see 3.1.12) to  $500 \text{ ml} \pm 10 \text{ ml}$  of water. Mix and cool to room temperature. Make up to  $1000 \text{ ml}$  with water.

## 3.2 Apparatus

### 3.2.1 Spectrometer, prism-, grating- or filter-type, capable of accepting optical cells of thickness 10 mm to 50 mm.

The spectrometer chosen shall be suitable for measuring absorbance in the visible and near infrared regions of the spectrum, the most sensitive wavelength being  $880 \text{ nm}$ , but if a loss of sensitivity can be accepted, absorbance can be measured at  $700 \text{ nm}$ .

NOTE The detection limit of the method is lower if a spectrometer capable of accepting  $100 \text{ mm}$  optical cells is available.

### 3.2.2 Filter assembly, to hold a membrane filter of nominal pore size $0,45 \mu\text{m}$ .

### 3.2.3 Preparation of glassware

Before use, wash all glassware with hydrochloric acid (see 3.1.12) at approximately  $40^\circ\text{C}$  to  $50^\circ\text{C}$  and rinse thoroughly with water. Do not use detergents containing phosphate.

Preferably the glassware should be used only for the determination of phosphorus. After use clean it as above and keep covered until needed again.

Rinse glassware used for the colour development stage occasionally with sodium hydroxide solution (see 3.1.4) to remove deposits of the coloured complex, which has a tendency to stick as a thin film on the wall of glassware.

### 3.3 Sampling and samples

#### 3.3.1 Sampling

Collect the laboratory samples in polyethylene, polyvinylchloride or preferably glass bottles. In the case of low phosphate concentrations, use glass bottles.

#### 3.3.2 Preparation of the test sample

Filter the laboratory sample (see 3.3.1) within 4 h after sampling. If the sample has been kept cool in the meantime, bring to room temperature before filtration.

Wash a membrane filter of nominal pore size 0,45 µm to ensure it is free of phosphate by passing 200 ml water, previously heated to approximately 30 °C to 40 °C. Discard these washings. Filter the sample and reject the first 10 ml of sample filtrate. Collect the remainder in a clean dry glass bottle for the immediate determination of orthophosphate (see 3.4.4).

If the filtrate is not within the range of pH 3 to 10, adjust it with sodium hydroxide solution (see 3.1.4) or sulfuric acid (see 3.1.3).

NOTE 1 The filtration time should not exceed 10 min. If necessary, a larger diameter filter should be used.

NOTE 2 The membrane filter should either be checked for phosphorus content or washed as described. Commercially available membrane filters that are sold free from phosphorus should be washed as described.

### 3.4 Procedure

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#### 3.4.1 Test portion

Take a volume of test portion not exceeding 40 ml. This maximum volume is suitable for the determination of orthophosphate concentrations of up to  $\rho_p = 0,8$  mg/l, when using an optical cell of thickness 10 mm. Use smaller test portions in order to accommodate higher phosphate concentrations as shown in Table 1. Similarly, low phosphate concentrations can be determined by measuring the absorbance in an optical cell of thickness 40 mm or 50 mm.

**Table 1 — Sample volumes and concentrations**

Orthophosphate concentration mg/l	Volume of test portion ml	Thickness of optical cell mm
0,0 to 0,8	40,0	10
0,0 to 1,6	20,0	10
0,0 to 3,2	10,0	10
0,0 to 6,4	5,0	10
0,0 to 0,2	40,0	40 or 50

#### 3.4.2 Blank test

Carry out a blank test in parallel with the determination, by the same procedure, using the same quantities of all the reagents as in the determination, but using the appropriate volume of water instead of the test portion.



### 3.4.3 Calibration

#### 3.4.3.1 Preparation of calibration solutions

Transfer, by means of a volumetric pipette, appropriate volumes, for example 1,0 ml; 2,0 ml; 3,0 ml; 4,0 ml; 5,0 ml; 6,0 ml; 7,0 ml; 8,0 ml; 9,0 ml and 10,0 ml, of the orthophosphate standard solution (see 3.1.11) to 50 ml volumetric flasks. Dilute with water to about 40 ml. These solutions represent orthophosphate concentrations  $\rho_p = 0,04$  mg/l to 0,4 mg/l.

Proceed accordingly for other ranges of phosphate concentrations shown in Table 1.

#### 3.4.3.2 Colour development

Add to each flask, while swirling, 1 ml ascorbic acid (see 3.1.5) followed by 2 ml of acid molybdate solution I (see 3.1.6). Make up to the mark with water and mix well.

#### 3.4.3.3 Spectrometric measurements

Measure the absorbance of each solution using the spectrometer (see 3.2.1) at 880 nm after between 10 min and 30 min, or if a loss of sensitivity can be accepted, at 700 nm. Use water in the reference cell.

#### 3.4.3.4 Plotting the calibration graph

Plot a graph of absorbance (as the y-axis) against the phosphorus content (as the x-axis) in milligrams of phosphorus per litre of the calibration solutions. The relationship between absorbance and concentration is linear. Determine the slope of the graph.

Verify the graph from time to time for linearity, especially if new batches of chemicals are used. Run an independently prepared calibration solution with each series of samples.

### 3.4.4 Determination

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#### 3.4.4.1 Colour development

Pipette the selected volume of test portion into a 50 ml one-mark volumetric flask and if necessary dilute to 40 ml  $\pm$  2 ml with water. Proceed as specified in 3.4.3.2.

If the test sample contains arsenate, this should be reduced to arsenite with thiosulfate in acidic medium. The reduction to arsenite is quantitative for arsenate concentrations up to at least 2 mg/l As, as described below.

Transfer, by means of a volumetric pipette, up to a maximum of 40 ml of the test sample to a 50 ml volumetric flask. Add 1 ml of ascorbic acid solution (see 3.1.5), and 1 ml of thiosulfate solution (see 3.1.9). Mix and allow the reduction to proceed for 10 min  $\pm$  1 min. Add 2 ml acid molybdate solution II (see 3.1.7). Make up to the mark with water. Mix well. Proceed as described in 3.4.3.2.

NOTE 1 If the test sample is turbid and/or coloured, the procedure described below is recommended.

Add 3 ml of the turbidity-colour compensation reagent (see 3.1.8) to the selected volume of test portion. Dilute to 50 ml and measure the absorbance. Subtract the absorbance of this solution from the value measured according to 3.4.3.3.

NOTE 2 Absorbance measured at 700 nm represents a loss of about 30 % of the sensitivity at 880 nm.

#### 3.4.4.2 Spectrometric measurements

See 3.4.3.3.

If, due to interference by arsenate, the test portion has been treated with thiosulfate, measurements should be taken within 10 min; otherwise the colour will fade.

### 3.5 Expression of results

#### 3.5.1 Calculation

Calculate the orthophosphate concentration,  $\rho_p$ , expressed in milligrams per litre, using the equation

$$\rho_P = \frac{(A - A_0) \cdot V_{max}}{f \cdot V_s}$$

where

- $A$  is the absorbance of the test portion;
- $A_0$  is the absorbance of the blank test;
- $f$  is the slope of the calibration graph (3.4.3.4), in litres per milligram;
- $V_{max}$  is the reference volume of the test portion (40 ml), in millilitres;
- $V_s$  is the actual volume of the test portion, in millilitres.

Report the mass concentrations of phosphorus as follows, but to not more than three significant figures:

$$\rho_p < 0,1 \text{ mg/l} \pm 0,001 \text{ mg/l};$$

$$0,1 \text{ mg/l} \pm 0,01 \text{ mg/l} \leq \rho_p < 10 \text{ mg/l} \pm 0,01 \text{ mg/l};$$

$$\rho_p \geq 10 \text{ mg/l} \pm 0,1 \text{ mg/l}.$$

#### 3.5.2 Precision

The precision data in Table A.1 were obtained in an interlaboratory trial involving 16 laboratories.

NOTE For interferences, see annex B.

### 3.6 Test report

The test report shall contain the following information:

- a) all information necessary for complete identification of the sample;
- b) a reference to this International Standard;
- c) a reference to the method used, and the number of the clause;
- d) the results obtained and
- e) details of any operations not included in this clause or regarded as optional, together with any incidents likely to have an influence upon the results.

## 4 Determination of orthophosphate after solvent extraction

This method can be applied only if the phosphate concentration in the sample is less than 0,01 mg/l P. The method is especially suitable for marine water.

### 4.1 Reagents

Use the reagents specified in 3.1.5 and 3.1.6, and in addition:

#### 4.1.1 1-Hexanol ( $C_6H_{13}OH$ ).

#### 4.1.2 Ethanol (C<sub>2</sub>H<sub>5</sub>OH).

#### 4.1.3 Orthophosphate, standard solution, $\rho = 0,5$ mg/l P.

Pipette 5,0 ml  $\pm$  0,01 ml of orthophosphate stock standard solution (see 3.1.10) into a 500 ml one-mark volumetric flask. Make up to the mark with water and mix well.

Prepare and use this solution each day it is required.

### 4.2 Sampling and samples

See 3.3.

### 4.3 Procedure

#### 4.3.1 Test portion

Transfer, by means of a measuring cylinder, 350 ml  $\pm$  5 ml of the test sample (see 3.3) to a 500 ml separating funnel.

#### 4.3.2 Blank test

Carry out a blank test in parallel with the determination, by the same procedure, using the same quantities of all reagents as in the determination, but using 350 ml of water instead of the test portion.

#### 4.3.3 Calibration

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##### 4.3.3.1 Preparation of calibration solutions

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Add 300 ml  $\pm$  10 ml of water to five individual separating funnels. From a microburette add 1,4 ml; 2,8 ml; 4,2 ml; 5,6 ml and 7,0 ml of orthophosphate standard solution (see 4.1.3) to each 500 ml separating funnel. Dilute each solution to 350 ml  $\pm$  10 ml with water, stopper, swirl and mix. These solutions represent orthophosphate concentrations,  $\rho_p$ , of 0,002 mg/l; 0,004 mg/l; 0,006 mg/l; 0,008 mg/l and 0,01 mg/l respectively.

##### 4.3.3.2 Colour development

To each separating funnel, with swirling, add 7,0 ml  $\pm$  0,1 ml of ascorbic acid solution (see 3.1.5) and 14,0 ml  $\pm$  0,1 ml of acid molybdate solution I (see 3.1.6).

After 15 min add 40,0 ml  $\pm$  0,1 ml of 1-hexanol (see 4.1.1) to each separating funnel and stopper. Shake vigorously for 1 min. Allow the phases to separate and pipette 30 ml  $\pm$  0,01 ml of each of the upper 1-hexanol extracts into a series of dry 50 ml one-mark volumetric flasks. Add 1,0 ml  $\pm$  0,2 ml ethanol (see 4.1.2) to each flask and dilute each solution to the mark with 1-hexanol.

##### 4.3.3.3 Spectrometric measurements

Measure the absorbance of each 1-hexanol solution at 680 nm in optical cells of thickness 40 mm or 50 mm against 1-hexanol in the reference cell.

##### 4.3.3.4 Plotting the calibration graph

Plot a graph of absorbance (as the y-axis) against the phosphorus content (as the x-axis), in milligrams per litre, of the calibration solutions. Determine the slope of the graph.

Verify the linearity of the calibration curve periodically, especially if new batches of chemicals are used.