

**NORME  
INTERNATIONALE  
INTERNATIONAL  
STANDARD**

**CEI  
IEC**

**60851-4**

**Edition 2.2**

2005-03

Edition 2:1996 consolidée par les amendements 1:1997 et 2:2005  
Edition 2:1996 consolidated with amendments 1:1997 and 2:2005

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**Fils de bobinage – Méthodes d'essai –**

**Partie 4:  
Propriétés chimiques**

**Winding wires – Test methods –**

**Part 4:  
Chemical properties**



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International Electrotechnical Commission, 3, rue de Varembe, PO Box 131, CH-1211 Geneva 20, Switzerland  
Telephone: +41 22 919 02 11 Telefax: +41 22 919 03 00 E-mail: inmail@iec.ch Web: www.iec.ch

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## INTERNATIONAL ELECTROTECHNICAL COMMISSION

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### WINDING WIRES – TEST METHODS –

#### Part 4: Chemical properties

#### FOREWORD

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International Standard IEC 60851-4 has been prepared by IEC technical committee 55: Winding wires.

This consolidated version of IEC 60851-4 consists of the second edition of IEC 60851-4 (1996) [documents 55/473A/FDIS and 55/514/RVD], its amendment 1 (1997) [documents 55/597/FDIS and 55/614/RVD] and its amendment 2 (2005) [documents 55/924/FDIS and 55/937/RVD].

The technical content is therefore identical to the base edition and its amendments and has been prepared for user convenience.

It bears the edition number 2.2.

A vertical line in the margin shows where the base publication has been modified by amendments 1 and 2.

The committee has decided that the contents of the base publication and its amendments will remain unchanged until the maintenance result date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

## INTRODUCTION

This part of IEC 60851 forms an element of a series of standards which deals with insulated wires used for windings in electrical equipment. The series has three groups describing:

- a) methods of test (IEC 60851);
- b) specifications (IEC 60317);
- c) packaging (IEC 60264).

## WINDING WIRES – TEST METHODS –

### Part 4: Chemical properties

#### 1 Scope

This part of IEC 60851 specifies the following tests:

- Test 12: Resistance to solvents;
- Test 16: Resistance to refrigerants;
- Test 17: Solderability;
- Test 20: Resistance to transformer oil.

For definitions, general notes on methods of test and the complete series of methods of test for winding wires see IEC 60851-1.

#### 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60296:1982, *Specification for unused mineral insulating oils for transformers and switchgear*

IEC 60554-1:1977, *Specification for cellulosic papers for electrical purposes – Part 1: Definitions and general requirements*

IEC 60851-1:1996, *Winding wires – Test methods – Part 1: General*

IEC 60851-3:1996, *Winding wires – Test methods – Part 3: Mechanical properties*

IEC 60851-5:1996, *Winding wires – Test methods – Part 5: Electrical properties*

#### 3 Test 12: Resistance to solvents (applicable to enamelled round wire with a nominal conductor diameter over 0,250 mm and applicable to enamelled rectangular wire)

The test is not suitable for round wires with a nominal conductor diameter up to and including 0,250 mm.

Resistance to solvents is expressed by the pencil hardness of the wire after solvent treatment.

##### 3.1 Equipment

The following solvents shall be used:

- standard solvent as specified below, or
- solvent as agreed between purchaser and supplier.

The standard solvent shall be a mixture of:

- 60 % by volume white spirit with maximum aromatic content of 18 %;
- 30 % by volume xylene;
- 10 % by volume butanol.

The pencil to be used shall be a lead pencil of a hardness as specified in the relevant standard. Before each test, the point of the pencil shall be sharpened with a smooth-cut file to form an angle of 60° symmetrical about the axis of the lead according to Figure 1.

### 3.2 Procedure

A straight piece of wire, approximately 150 mm in length, shall be preconditioned for  $(10 \pm 1)$  min at  $(130 \pm 3)$  °C in an oven with forced air circulation. A substantial length of the wire shall then be immersed in standard solvent contained in a glass cylinder and shall be maintained therein at a temperature of  $(60 \pm 3)$  °C for a period of  $(30 \pm 3)$  min. The wire shall then be removed from the solvent. The hardness of the wire surface shall then be determined in the following manner within a period of 30 s after removal from the solvent.

The specimen to be tested shall be laid on a smooth hard surface according to Figure 1. In the case of rectangular wires, the test shall be carried out on the largest side of the wire. The pencil shall be placed on the surface of the wire at an angle of approximately  $(60 \pm 5)$ ° and the sharpened edge shall be pressed slowly along the surface of the wire with a force of approximately  $(5 \pm 0,5)$  N.

Three tests shall be made. It shall be reported, if the coating is removed with exposure of the bare conductor.

NOTE 1 This method can also be used for testing resistance to other fluids, for example oil.

NOTE 2 Where it is desired to determine the hardness of the insulation, the hardness of the lead pencil which just fails to remove the coating from the surface of the conductor shall be taken as the hardness of the wire surface, expressed by the pencil hardness. The pencil hardness series is as follows:

6B	5B	4B	3B	2B	B	HB	H	2H	3H	4H	5H	6H	7H	8H	9H
4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

## 4 Test 16: Resistance to refrigerants (applicable to enamelled round wire)

Resistance to refrigerant is expressed by the quantity of matter extracted from the coating of the wire and by the breakdown voltage after exposure to a refrigerant.

NOTE 1 The data in this test method apply to monochlorodifluoromethane (refrigerant R 22). Other refrigerants may be used, in which case the critical data for such fluid should be observed and operation of the pressure vessel should comply with the revised test conditions.

NOTE 2 Refrigerants like monochlorodifluoromethane and rinsing fluids like trichlorotrifluorethane (refrigerant R 113) are ozone depleting chemicals (ODC). Refrigerant and rinsing fluid should be agreed upon between customer and supplier.

### 4.1 Extraction

#### 4.1.1 Principle

A siphon cup containing the wire sample is placed in the pressure vessel. The extractable matter is determined after exposure of the wire sample to the refrigerant under pressure and at elevated temperature.



#### 4.1.2 Equipment

The following equipment shall be used:

- siphon cup according to Figure 2, of 450 ml volume up to the siphoning level;
- pressure vessel of 2 000 ml volume with an internal diameter of approximately 100 mm and a pressure capacity of 200 bar (20 MPa), preferably of unwelded construction and provided with a controlled heating system;
- top closure of the vessel containing a condenser coil according to Figure 3;
- oven with forced air circulation.

#### 4.1.3 Specimen

Eight wire samples each containing  $(0,6 \pm 0,1)$  g of insulation shall be wound into coils of 70 turns. The specimens shall be degreased and conditioned in an oven with forced air circulation at  $(150 \pm 3)$  °C for 15 min. After 30 min cooling, the eight specimens shall be weighed together to the nearest 0,0001 g, resulting in the total initial mass  $M_1$ .

#### 4.1.4 Procedure

The eight specimens shall be placed in the siphon cup, which is suspended  $(25 \pm 5)$  mm below the condenser coil on the pressure vessel cover. The pressure vessel shall be assembled and charged with  $(700 \pm 25)$  g of distilled refrigerant free from lubricant. The condenser water supply and drain line shall be connected and the pressure vessel shall be heated by means of a controlled heating system with the temperature set to  $(75 \pm 5)$  °C or a lower temperature if required to comply with the conditions of the following paragraph relating to critical pressure. The water flowing through the condenser shall be adjusted to maintain a reflux rate of 20 to 25 discharges per hour from the siphon cup. The extraction period shall be 6 h.

The pressure in the vessel shall not exceed 75 % of the critical pressure of the refrigerant chosen. Therefore, prior to use, the over-pressure control valve shall be checked to ensure its proper functioning.

NOTE It is recommended that the heating system be automatically deactivated if the pressure exceeds 75 % of the critical pressure of the refrigerant chosen or if the water flow through the condenser coil is interrupted.

At the end of the extraction period the pressure vessel shall be cooled. The refrigerant shall be removed from the pressure vessel and recovered using suitable means such as a refrigerant compressor and recovery system. The pressure shall be released and the pressure vessel opened.

For the following operations, the rinsing fluid shall be distilled before use.

The specimens and siphon cup shall be rinsed with the agreed rinsing fluid, the rinse poured into the pressure vessel and the walls of the pressure vessel washed with two successive rinses each of 100 ml of rinsing fluid. The fluid shall then be evaporated to  $(5 \pm 1)$  mm from the bottom of the pressure vessel and recovered in a safe manner.

The liquid sample shall be transferred to a pre-dried tared aluminium weighing dish and the pressure vessel rinsed with 15 ml of rinsing fluid, which is transferred to the dish and then evaporated to dryness at  $(150 \pm 3)$  °C for 60 to 65 min. The weighing dish shall then be cooled to room temperature in a desiccator. The dish with the residue shall be weighed to the nearest 0,0001 g and the original tared mass of the same dish subtracted. The difference is the total residue mass  $M_2$  of the matter extracted from the eight specimens.

The insulation on the coils shall be removed by suitable chemical means not affecting the conductor and the bare conductors shall be dried at  $(150 \pm 3) ^\circ\text{C}$  for  $(15 \pm 1)$  min and cooled to room temperature in a desiccator. They shall be weighed to the nearest 0,0001 g and the mass of the eight conductors together is the total conductor mass  $M_3$ .

#### 4.1.5 Result

The extractable matter shall be determined according to the following equation:

$$\text{Extractable matter} = \frac{M_2}{M_1 - M_3} \times 100 \%$$

One test shall be made. The masses  $M_1$ ,  $M_2$ ,  $M_3$ , the refrigerant, rinsing fluid, temperature, pressure of the pressure vessel and the percentage extractable matter shall be reported.

## 4.2 Breakdown voltage

### 4.2.1 Principle

A specimen prepared according to 4.4.1 of IEC 60851-5 is placed in a pressure vessel according to 4.2.2. The breakdown voltage is determined after exposure of the specimen to the refrigerant under pressure and at elevated temperature.

### 4.2.2 Procedure

The specimen shall be conditioned in the oven  $(150 \pm 3) ^\circ\text{C}$  for 4 h and then placed in the pressure vessel, which shall be assembled and charged with  $(1\,400 \pm 50)$  g of refrigerant. The pressure vessel shall be heated according to 4.1.4 of this standard but for a period of  $(72 \pm 1)$  h.

At the end of the exposure period, the pressure vessel shall be cooled and discharged as described under 4.1.4. When the pressure inside the tube is less than 2 bar (0,2 MPa) absolute, the pressure vessel shall be opened and the specimen, within a period of 25 s to 30 s, transferred to the oven at a temperature of  $(150 \pm 3) ^\circ\text{C}$ . The specimen shall remain in the oven for  $(10 \pm 1)$  min. After the specimen is removed from the oven and allowed to cool to room temperature, the breakdown voltage shall be determined according to 4.4.1 of IEC 60851-5.

### 4.2.3 Result

Five specimens shall be tested. The five individual values shall be reported.

## 5 Test 17: Solderability (applicable to enamelled round wire and bunched wire)

Solderability is expressed by the time of immersion of the specimen in a solder bath required to remove the coating and to coat the conductor with solder.

**Safety warning:** Chemical hazard – Lead has been recognized by regulatory agencies to be a hazardous substance. Primary routes of exposure are by inhalation and ingestion. The information contained in the Material safety data sheet (MSDS) for lead, tin, flux and alcohol must be adhered to while using, handling or disposing of these products. Adequate ventilation or forced exhausting of solder pot vapours and products of decomposition from various solderable insulations may be necessary to comply with environmental regulations.

**Safety warning:** Thermal hazard – Care must be exercised in removing test specimens from the solder pot to avoid skin burns.

## 5.1 Equipment

The following equipment shall be used:

- temperature controlled solder bath of sufficient volume to maintain a constant solder temperature when immersing the specimen at any temperature specified in the relevant standard. Solder composition shall be of a mass ratio of 60 parts tin to 40 parts lead;
- any specimen holder that holds the wire under test free for at least 20 mm between the points of support when immersed into the solder. The material used for the specimen holder shall be such that the solder does not undergo any contamination and the dimensions of the holder shall not lead to significant change of the bath temperature during immersion.

NOTE Contamination of the solder due to oxidation or from copper may affect the results.

## 5.2 Equipment

The following equipment shall be used:

- Temperature controlled solder bath of sufficient volume to maintain a constant solder temperature when immersing the specimen at any temperature specified in the relevant standard. Solder composition shall be of a mass ratio of 60 parts tin to 40 parts lead; any dross which forms shall be removed from the surface of the solder before each test; the temperature shall be controllable with  $\pm 5$  °C of the relevant specification temperature.
- Any suitable carrier that allows the wire to be held free for at least  $(35 \pm 5)$  mm between the points of support (see Figure 4). The material used for the carrier shall be such that the solder bath does not undergo any contamination. The dimensions of the carrier shall not lead to appreciable changes in the bath temperature during immersion.

NOTE Contamination of the solder due to oxidation or from copper may affect the results.

## 5.3 Procedure

The specimen shall be held vertically over the centre of the bath maintained at the temperature as specified in the relevant standard. The bottom end shall be lowered to  $(35 \pm 5)$  mm below the surface of the bath. The position at which the specimen is immersed shall be within 10 mm of the point where the temperature is measured. After immersion for the time specified in the relevant specification sheet, the specimen shall be moved sideways in the bath before it is withdrawn from the solder.

The surface of the tinned wire shall be examined with a magnification of 6X to 10X. In the case of wire up to and including 0,100 mm nominal conductor diameter, the examination shall be restricted to the centre  $(25 \pm 2,5)$  mm free length section between the supports. In the case of wire over 0,100 mm nominal conductor diameter and bunched wires, the examination shall be restricted to the lower 15 mm of the segment immersed in the pot.

Three specimens shall be tested. The condition of the surface of the wire shall be reported.

## 6 Test 20: Resistance to hydrolysis and to transformer oil (applicable to enamelled wire)

Resistance to hydrolysis is expressed by appearance and adherence after exposure of the specimens to transformer oil in the presence of water under pressure and at elevated temperature.

Resistance to transformer oil is expressed by breakdown voltage and flexibility after exposure of the specimens to transformer oil under pressure and at elevated temperature.

NOTE The water may affect the coating by hydrolytic degradation and/or by absorption. If only absorption has occurred, drying the specimen at  $125\text{ }^{\circ}\text{C} \pm 3\text{ }^{\circ}\text{C}$  for 30 min prior to the breakdown voltage test will produce a recovery of the specimen. Wire with a nominal conductor diameter between 0,800 mm and 1,500 mm has been generally found convenient to handle and to test.

### 6.1 Round wire

#### 6.1.1 Equipment

The following equipment shall be used:

- two glass tubes of 25 mm diameter and 300 mm length capable of being sealed;
- stainless steel pressure vessel of 400 ml to 500 ml volume with a pressure capacity of  $6 \times 10^6$  Pa, preferably of unwelded construction and provided with a controlled heating system;
- transformer oil according to IEC 60296;
- paper according to IEC 60554-1, type 1.

#### 6.1.2 Specimens

The following specimens shall be prepared:

- 12 straight pieces of wire with a length of approximately two-thirds of the internal height of pressure vessel;
- 10 twisted pair specimens prepared in accordance with 4.4.1 of IEC 60851-5 for nominal conductor diameter up to and including 2,500 mm or 10 straight specimens tested in accordance with 4.5.1 of IEC 60851-5 for nominal conductor diameter over 2,500 mm;
- 3 mandrel-wound specimens prepared in accordance with 5.1.1 of IEC 60851-3 for nominal conductor diameter up to and including 1,600 mm or 3 straight specimens tested in accordance with 5.2 of IEC 60851-3 for a nominal conductor diameter over 1,600 mm.

#### 6.1.3 Procedure

##### 6.1.3.1 Resistance to hydrolysis

Six straight pieces of wire prepared according to 6.1.2 are placed in the pressure vessel together with a quantity of de-aerated dry transformer oil sufficient to occupy  $(52,5 \pm 2,5)\%$  of the volume of the pressure vessel. The pressure vessel shall be sealed and heated to  $(150 \pm 3)\text{ }^{\circ}\text{C}$  for  $(24 \pm 1)$  h, after which it is allowed to cool to room temperature before opening. The specimens shall be examined with normal vision. The test shall be repeated with a quantity of water equal to  $(0,3 \pm 0,1)\%$  of the volume of oil used being added to the pressure vessel.

One test shall be made. Any changes in appearance and adherence shall be reported

### 6.1.3.2 Resistance to transformer oil

Depending on the diameter and according to 6.1.2, the pressure vessel shall contain 10 twisted pair or straight specimens, three mandrel-wound or straight specimens and extra pieces of wire to arrive at the volume of coating<sup>1</sup> specified in Table 1. The pressure vessel shall be charged in accordance with the components and quantities specified in Table 1. Immediately prior to their addition, the oil and paper shall be dried and the oil de-aerated at a pressure of 2 kPa for  $(16 \pm 1)$  h at  $(90 \pm 3)$  °C or for  $(4 \pm 0,30)$  h at  $(105 \pm 3)$  °C.

**Table 1 – Volume of components**

Component	Container volume %
Transformer oil	$65 \pm 5$
Paper	$4 \pm 1$
Coating	$0,275 \pm 0,075$
Steel	*
* By agreement between purchaser and supplier.	

The sealed pressure vessel shall be heated to the class temperature of the wire  $\pm 3$  °C, or to  $(150 \pm 3)$  °C, if class temperature is higher than 150 °C, and maintained for  $(1\,000 \pm 10)$  h. The pressure vessel shall then be allowed to cool to room temperature, discharged and opened. Five of the 10 specimens shall be tested at  $(105 \pm 3)$  °C for breakdown voltage with the specimens in air in accordance with either 4.4.2 or 4.5.2 of IEC 60851-5, depending on the conductor diameter. The remaining five of the 10 specimens shall be dried at  $(125 \pm 3)$  °C for  $(30 \pm 5)$  min, allowed to cool to room temperature and then tested at  $(105 \pm 3)$  °C for breakdown voltage in air in accordance with either 4.4.2 or 4.5.2 of IEC 60851-5, depending on the conductor diameter.

The three specimens shall be examined for cracks according to either 5.1.1.1 or 5.2 of IEC 60851-3, depending on the conductor diameter.

One test shall be made. The individual values of breakdown voltage and any cracks shall be reported.

## 6.2 Rectangular wire

### 6.2.1 Equipment

Equipment according to 6.1.1 shall be used.

<sup>1</sup> The total mass of wire in grams to provide the required volume of enamel can be calculated approximately by:

$$M = \frac{Y \times V}{600 \times \delta \times D}$$

where

$V$  is the volume of the pressure vessel in millilitres;

$Y$  is the mass of 1 m of wire in grams;

$\delta$  is the increase in diameter due to the coating in millimetres;

$D$  is the overall diameter of the wire in millimetres.

## 6.2.2 Specimens

The following specimens shall be prepared:

- 10 straight pieces of wire with a length of approximately two-thirds of the internal height of pressure vessel;
- four U-shaped specimens prepared in accordance with 4.7.1 of IEC 60851-5;
- two mandrel bent specimens prepared in accordance with 5.1.2 of IEC 60851-3.

## 6.2.3 Procedure

### 6.2.3.1 Resistance to hydrolysis

Each of the tubes shall be charged with five straight pieces of wire according to 6.2.2 and 80 ml de-aerated dry transformer oil. To one of the tubes, 0,24 ml  $\pm$  0,01 ml of distilled water shall be added. The two tubes shall be sealed and placed in an oven for 24 h at 150 °C  $\pm$  3 °C. The tubes shall then be removed from the oven, and then allowed to cool down to room temperature and opened. The specimens shall be examined with normal vision.

One test shall be made. Any changes in appearance and adherence shall be reported.

### 6.2.3.2 Resistance to transformer oil

The pressure vessel shall contain four U-shaped specimens, two mandrel bent specimens and extra pieces of wire to arrive at the volume of coating<sup>2</sup> specified in Table 1. The pressure vessel shall then be charged, in accordance with the quantities specified in Table 1, with oil and paper which shall have been dried separately immediately prior to addition at a pressure of maximum 2 kPa for (16  $\pm$  1) h at (90  $\pm$  3) °C or for (4  $\pm$  0,1) h at (105  $\pm$  3) °C. The sealed pressure vessel shall be heated to the class temperature of the wire  $\pm$  3 °C, or to (150  $\pm$  3) °C if class temperature is higher than 150 °C, and maintained for (1 000  $\pm$  10) h. The pressure vessel shall then be allowed to cool to room temperature, discharged and opened. Two of the U-shaped specimens shall be tested at (105  $\pm$  3) °C for breakdown voltage in air in accordance with 4.7.2 of IEC 60851-5. The remaining two of the U-shaped specimens shall be dried at (125  $\pm$  3) °C for (30  $\pm$  5) min, allowed to cool to room temperature and then tested at (105  $\pm$  3) °C for breakdown voltage in air according to 4.7.2 of IEC 60851-5.

The mandrel-bent specimens shall be examined for cracks according to 5.1.2 of IEC 60851-3.

One test shall be made. The individual values of breakdown voltage and any cracks shall be reported.

<sup>2</sup> The total mass of wire in grams to provide the required volume of enamel can be calculated approximately by:

$$M = \frac{Y \times V}{385 \times \delta \times (W + T)}$$

where

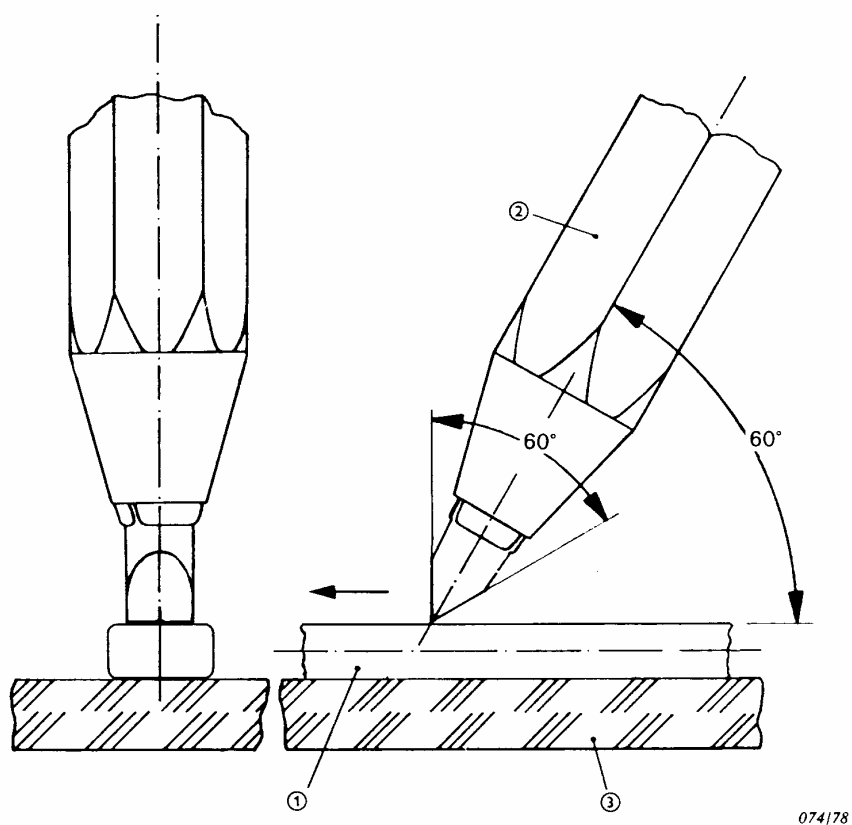
$V$  is the volume of the pressure vessel in millilitres;

$Y$  is the mass of 1 m of wire in grams;

$\delta$  is the increase in thickness due to the coating in millimetres;

$W$  is the overall width of the wire in millimetres;

$T$  is the overall thickness of the wire in millimetres.



NOTE Angle tolerances  $\pm 5^\circ$ .

**Figure 1 – Pencil and specimen for solvent test**



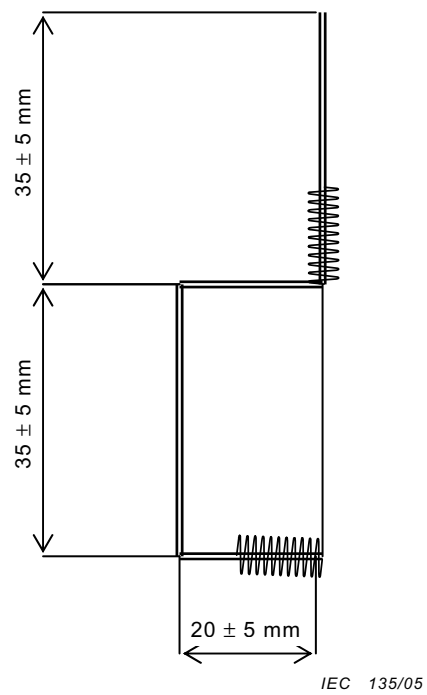
Height of cup:	$(82 \pm 5)$ mm
Diameter of cup:	$(84 \pm 5)$ mm
Diameter of tubing:	$(5 \pm 1)$ mm

**Figure 2 – Refrigerant extractable test siphon cup**





**Figure 3 – Condenser coils**



**Figure 4 – Example of carrier for solderability test**