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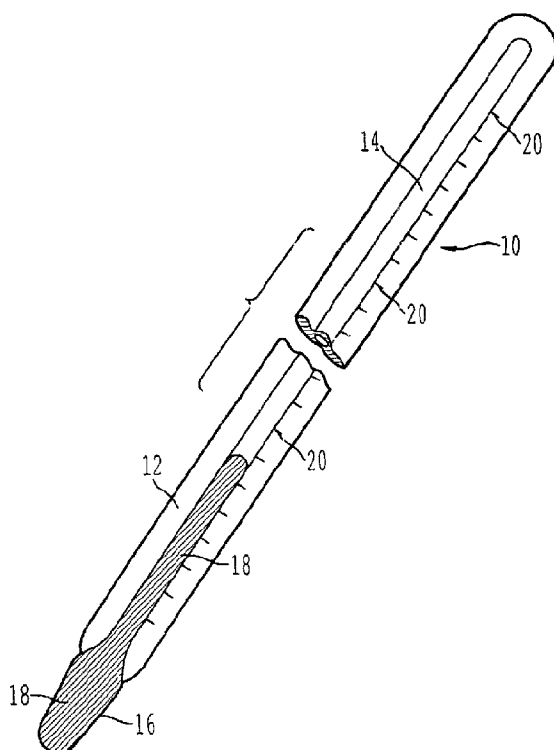
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[Continued on next page]

(54) Title: IONIC LIQUID TEMPERATURE SENSOR



(57) Abstract: A temperature sensor (10) having a capillary tube or stem (12), sealed at both ends, with a thin bore (14) defined therein is applied to the measurement of temperatures having a range of about 100° to +400° Centigrade. A bubble (16) comprising a liquid reservoir, is provided at one end of the capillary tube (12), in liquid communication with the bore (14), and is generally filled with an ionic thermometric liquid (18). In the operation of the temperature sensor (10), temperature is measured by the height of the liquid (18) in the bore (14).

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IONIC LIQUID TEMPERATURE SENSOR

5 TECHNICAL FIELD

This invention relates to a temperature sensor, and more particularly to a temperature sensor comprising a holder and an ionic liquid contained therein.

10

BACKGROUND OF THE INVENTION

Various types of temperature sensors are known including liquid-in-glass (LIG) thermometers, bimetallic thermometers, resistance thermometers, 15 thermocouples, and radiometers. Depending upon the temperature to be measured, the required accuracy of the measurement, and other factors such as durability or cost, one type of temperature sensor may be preferable over another.

20 For instance, LIG thermometers are standard equipment at laboratories and surface weather stations. LIG thermometers have a fine glass bore and a fluid reservoir. Operation depends on the thermal expansion of the liquid contained in the glass envelope. The sensitivity of the LIG 25 thermometer depends inversely on the diameter of the bore of the tube and on the relative expansion coefficients of the liquid and glass. The desired temperature range is the main criterion in the choice 30 of the thermometric liquid.

The most common liquids used in LIG thermometers are the molecular liquids mercury (Hg) and ethanol. Hg LIG thermometers are inexpensive,

durable, accurate and easily calibrated. Another advantage of the Hg LIG thermometer is its high temperature range (the upper operating temperature limit for a Hg LIG thermometer is about 350 °C).

- 5 Several disadvantages are that Hg is not be useful in low temperature situations because Hg freezes at about -39 °C, that Hg responds slowly in response to changes in temperature, and that Hg is highly volatile and toxic at low concentrations. Hg also
10 poses an environmental hazard associated with the storage and disposal of broken Hg LIG thermometers.

For temperature measurements below -39°C, LIG thermometers containing ethanol are commonly used. The ethanol LIG thermometer has a freezing
15 point of about -110 °C and a boiling point of about 78 °C. Ethanol has a faster response time and is less hazardous than Hg. However, fluid loss by evaporation is hard to avoid with ethanol and the upper operating temperature of 78°C limits the
20 utility of ethanol LIG thermometers over a wide temperature range.

For many applications, the desirable temperature range is -70 to 370 °C. Therefore, two LIG thermometers must used in such a situation, an
25 ethanol thermometer for low temperatures and a Hg thermometer for high temperatures.

In addition to the LIG thermometer, another commonly used temperature sensor is the bimetallic thermometer. Bimetallic thermometers are found in
30 household central heating and air conditioning systems. Bimetallic thermometers rely on the differential thermal expansion of two metals bound together in a strip. They are cheap, durable, easily

calibrated and can be used for thermographs. However, they require frequent calibration to maintain accuracy and they exhibit slow response times.

5 Yet another commonly used temperature sensor is the thermocouple. Thermocouples are used for *in situ* observations at locations wired to a computer network. Electrical and electronic thermometric devices deliver a rapid response, are
10 durable and accurate over a broad temperature range. However, thermocouple and thermistor devices require expensive ancillary equipment and electronics to operate.

 Still another device for temperature
15 measurement is the radiometer. Radiometers are used for remote temperature observations. Radiometers permit measurement of temperature by detecting the absorption of emitted radiation. They are expensive specialist devices most commonly used for remote
20 sensing on meteorological satellites.

 The present invention provides one solution to the limitations of the currently available temperature sensors as is discussed in the disclosure that follows. Here, a temperature sensor comprised
25 of a holder containing an ionic liquid delivers a wider working temperature range than most other temperature sensors, is economical, easy to calibrate, and the ionic liquid has low toxicity.

30 BRIEF SUMMARY OF THE INVENTION

 The present invention is directed to a temperature sensor comprised of an ionic liquid or mixtures thereof contained inside a holder.

In one embodiment, the temperature sensor is a holder using a thermometric liquid. The sensor comprises a thermometer having an elongated vessel and a reservoir for liquid. The thermometer, 5 further, comprises a bore, within the elongated vessel, the bore being in liquid communication with the reservoir. In a preferred embodiment, a plurality of graduations are associated with the elongated vessel, such that the graduations can 10 express a range of temperatures equivalent to about -100° to about +400° Centigrade. The liquid in the thermometer rises or falls, within the bore, depending on the temperature ambient to the thermometer.

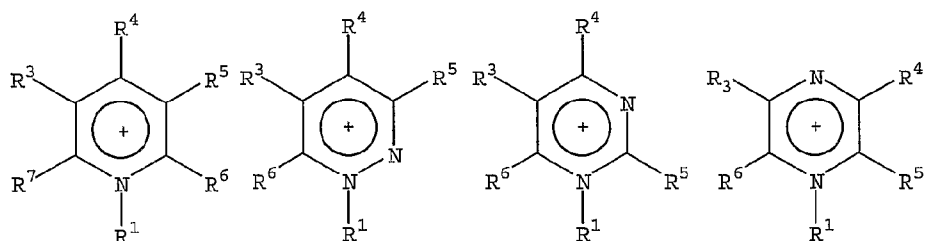
15 In a preferred embodiment of the present invention the liquid is a thermometric ionic liquid that includes either a contrast or coloring medium or dye such that the level of the liquid in the bore can be more easily seen. As a result of the use of the 20 ionic liquids of the present invention, the thermometer can measure temperatures in a range of about -100° to about +400° Centigrade.

In a temperature sensor of a preferred embodiment, the space within the bore is a vacuum. 25 Further, as a result of the liquid used, the volume of liquid in the bore is dependent on temperature.

Also, the temperature sensor of the preferred embodiment can be created from a transparent material, such as glass or plastic.

30 The ionic liquid is made up of organic cations and either inorganic or organic anions or mixtures thereof.

A cation of an ionic liquid is preferably one whose structure corresponds to a formula selected from the group consisting of



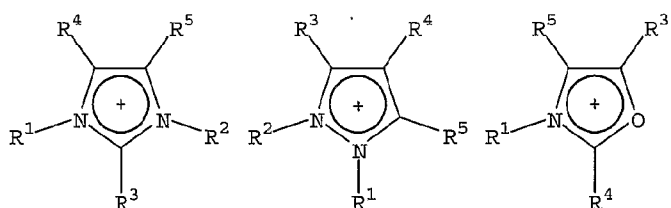
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PYRIDINIUM

PYRIDAZINIUM

PYRIMIDINIUM

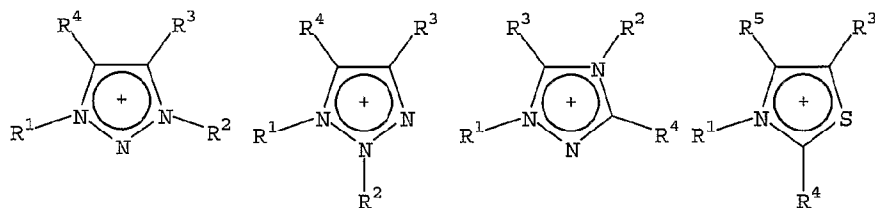
PYRAZINIUM



IMIDAZOLIUM

PYRAZOLIUM

OXAZOLIUM

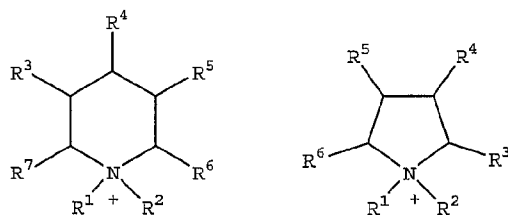


1,2,3-TRIAZOLIUM

1,2,4-TRIAZOLIUM

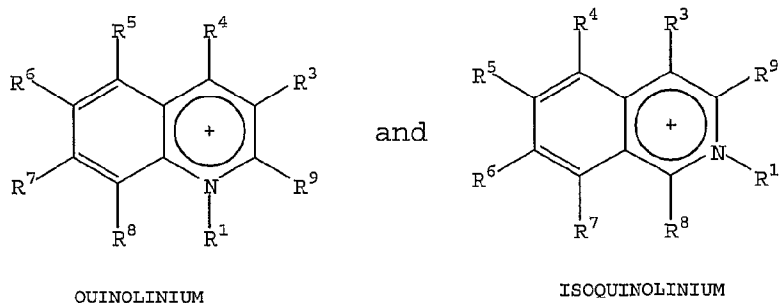
THIAZOLIUM

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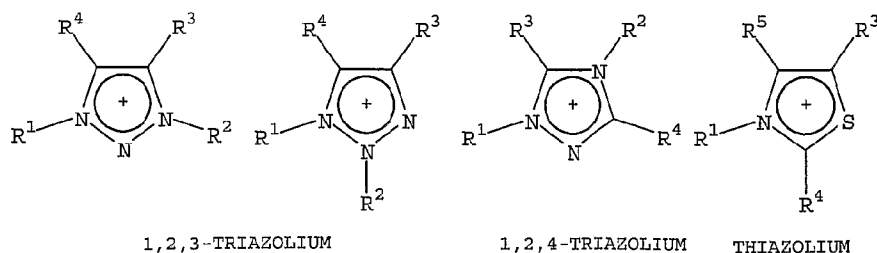
PIPERIDINIUM

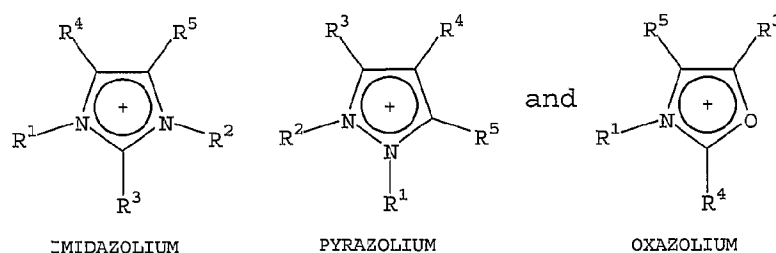
PYRROLIDINIUM



wherein R^1 and R^2 are independently hydrido, a C_1 - C_6 alkyl group or a C_1 - C_6 alkoxyalkyl group, and R^3 , R^4 , R^5 , R^6 , R^7 , R^8 and R^9 (R^3 - R^9),
 5 when present, are independently a hydrido, a C_1 - C_6 alkyl, a C_1 - C_6 alkoxyalkyl group or a C_1 - C_6 alkoxy group. It is to be noted that there are two isomeric 1,2,3-triazoles. It is preferred that all R groups not required for cation formation be hydrido.

10 A cation that contains a single five-membered aromatic ring that is free of fusion to other ring structures is more preferred. Exemplary cations are illustrated below wherein R^1 , R^2 , and R^3 - R^5 , when present, are as defined before. A preferred
 15 organic cation is a 1- C_1 - C_6 -alkyl-3-methylimidazolium or a C_1 - C_6 alkoxyalkyl-3-methylimidazolium cation.





The anions of the ionic liquid can be hydrophilic or hydrophobic. An illustrative anion is selected from the group consisting of a halogen, pseudohalogen, a C₁-C₆ carboxylate, tetrafluoroborate, hexafluorophosphate, a polyfluoro C₂-C₆ carboxylate, bis(trifluoromethanesulfonyl)imide, trifluoromethanesulfonate, and the like.

A preferred ionic liquid is 1-butyl-3-methylimidazolium bis(trifluoromethanesulfonyl)imide ([C₄mim][Tf₂N]). Another preferred ionic liquid is 1-ethyl-3-methylimidazolium tetrafluoroborate ([C₂mim][BF₄]).

In another embodiment, a first ionic liquid is combined with a second ionic liquid in order to reduce viscosity and depress the solidification point. The second ionic liquid can be a colored ionic salt such as imidazolium tetrachlorometallate salts.

In yet another embodiment, a solvent (non-ionic liquid) can be added to the ionic liquid.

BRIEF DESCRIPTION OF THE DRAWING

Figure 1 is a perspective view of a temperature sensor of the present invention.

DETAILED DESCRIPTION OF AN ILLUSTRATIVE

EMBODIMENT OF THE PRESENT INVENTION

Although the present invention is susceptible of embodiment in various forms, there is shown in the drawing a presently preferred embodiment
5 that is discussed in greater detail hereafter. It should be understood that the present disclosure is to be considered as an exemplification of the present invention, and is not intended to limit the invention to the specific embodiment illustrated. It should be
10 further understood that the title of this section of this application ("Detailed Description of an Illustrative Embodiment of the Device of Present Invention") relates to a requirement of the United States Patent Office, and should not be found to
15 limit the subject matter disclosed herein.

Referring now to the drawing, a typical temperature sensor, commonly referred to as a thermometer 10 is shown. Thermometer 10 is of the "liquid-in-glass" type thermometer that commonly
20 contain thermometric, or temperature sensitive, liquid such as mercury or alcohol. It will be understood, by persons having skill in the art, that while "glass" has been used in the description of the present invention, any thermal conductive materials,
25 having typical thermometer properties (such as transparency, strength, scratch resistance, ability to withstand sterilization, etc.), such as certain plastics, may be used without departing from the novel scope of the present invention.

30 Thermometer 10 comprises a capillary tube or stem 12, sealed at both ends, having a, typically thin, bore 14 defined therein. A bulb 16, comprising a liquid reservoir, is provided at one end of

capillary tube 12, and is generally filled with a thermometric liquid 18. Bulb 16, which seals the first end of capillary tube or stem 12, is in communication with bore 14, and bore 14 can be
5 formed, integrally, with bulb 16. In the operation of a liquid-in-glass thermometer, temperature is measured by the height of the liquid in bore 14. The liquid 18 is caused to rise, or fall, as a result in the change in pressure, within bore 14, caused by the
10 increase or decrease in the temperature of the body being measured.

Liquid 18 is preferably colored so that it can be easily seen within the capillary tube or stem 12 of the thermometer 10. It will be understood by
15 persons having skill in the art that a naturally colored thermometric liquid, or one that naturally provides a contrast with the materials used to make-up the capillary tube or stem 12 of a thermometer 10, can be used, without addition of color or contrast
20 materials, without departing from the novel scope of the present invention.

In the present invention, an ionic liquid is the thermometric liquid 18 used in thermometer 10. A more detailed discussion of a contemplated ionic
25 liquid useful in the present invention is provided below.

Thermometer 10 further comprises graduations 20, of the type typically found on thermometers, to provide a means for determining the
30 temperature of the body being tested. It will be understood, by persons having ordinary skill in the art, that the graduations provided can be of any temperature scale, including but not limited to

Centigrade or Fahrenheit, without departing from the novel scope of the present invention. Further, the graduations, which can be of any size, shape or color, can be applied to thermometer 10 (or any part thereof or associated therewith) in any manner known in the art, including by etching the graduations onto the thermometer body, painting the graduations thereon, using decals, associating the thermometer with a backing material having a scale thereon, or associating the thermometer with projected or electronic graduations, all without departing from the novel scope of the present invention.

In a preferred embodiment of the present invention, the graduations include a range of graduations of between about -100° and about +400° Centigrade. It also will be understood that thermometer 10, of the present invention, can be constructed without graduations, without departing from the novel scope of the present invention.

Ionic liquids are liquids comprised of discrete ions having substantially no vapor pressure and an exceptionally wide temperature range that can be from about -90°C to about 400°C. [Holbrey et al., *Clean Prod. Proc.*, 1999, 1, 233; Welton, *Chem. Rev.*, 1999, 99, 2071; Keim et al., *Angew. Chem. Int. Ed.*, 2000, 39, 3772].

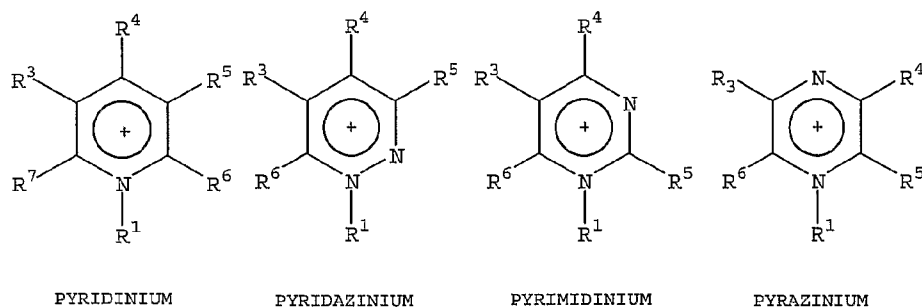
Most ionic liquids are comprised of an organic cation and an anion that can be inorganic or organic, but is usually weakly coordinating or contains a diffuse negative charge. The range of available ionic liquids is vast and potentially unlimited. About 10^{18} individual ionic liquids can be prepared by simple variations in the alkyl-chain

substitution patterns of the cations currently
utilized for the preparation of ionic liquids
[Holbrey et al., *Clean Prod. Proc.*, **1999**, *1*, 233].

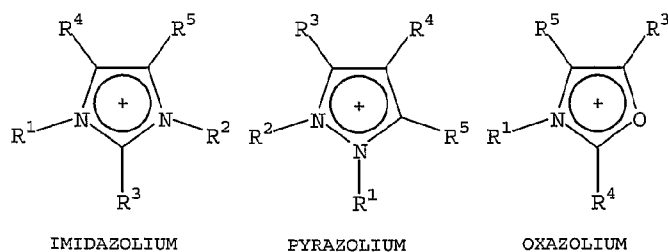
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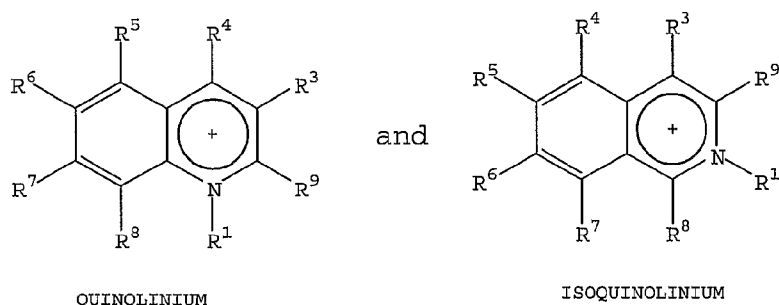
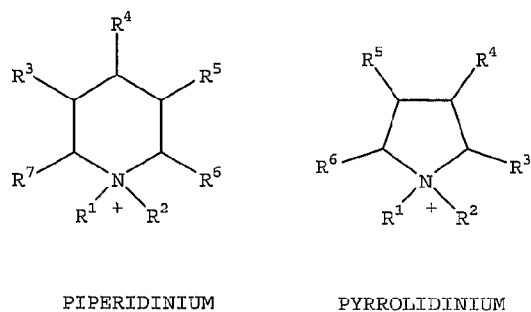
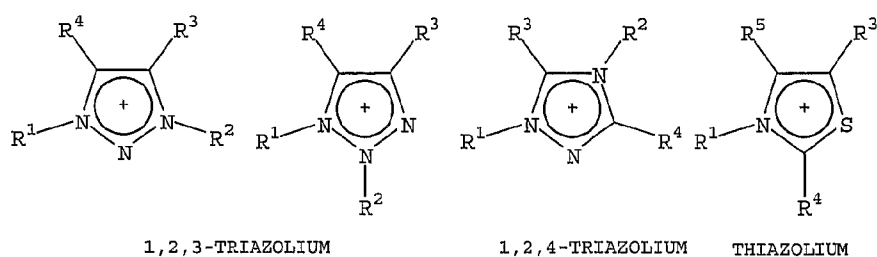
- 5 underestimated if other substituents, for example
alkyloxy chains, cation types, anion types, and
mixtures of two or more cations, anions or both are
considered.

The most common organic cations used in
10 ionic liquids are substituted pyridinium,
pyridazinium, pyrimidinium, pyrazinium, pyrazolium,
imidazolium, oxazolium, triazolium, thiazolium,
pyrrolidinium, piperazinium, quinolinium,
isoquinolinium, ammonium, and phosphonium
15 derivatives. A cation of an ionic liquid preferably
corresponds in structure to a formula selected from
the group consisting of



20





5

wherein R^1 and R^2 are independently hydrido, a C_1 - C_6 alkyl group or a C_1 - C_6 alkoxyalkyl group, and R^3 , R^4 , R^5 , R^6 , R^7 , R^8 and R^9 (R^3 - R^9), when present, are independently a hydrido, a C_1 - C_6 alkyl, a C_1 - C_6 alkoxyalkyl group or a C_1 - C_6 alkoxy group. More preferably, both R^1 and R^2 groups are C_1 - C_4 alkyl, with one being methyl, and R^3 - R^9 , when present, are preferably hydrido. It is preferred that all R groups not required for cation formation

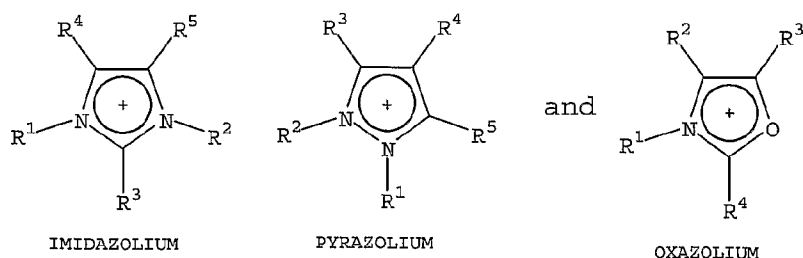
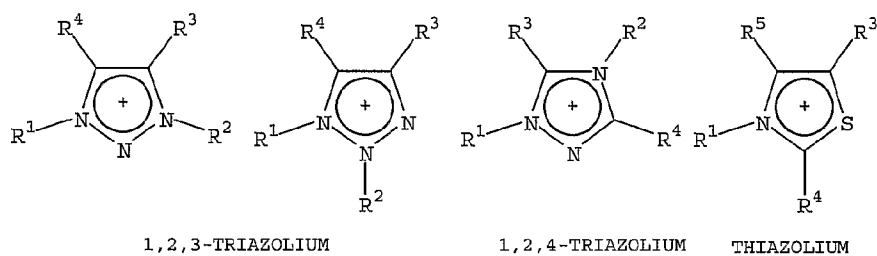
10

15 be hydrido.

Exemplary C_1 - C_6 alkyl groups and C_1 - C_4 alkyl groups include methyl, ethyl, propyl, iso-

propyl, butyl, sec-butyl, iso-butyl, pentyl, iso-pentyl, hexyl, 2-ethylbutyl, 2-methylpentyl and the like. Corresponding C₁-C₆ alkoxy groups contain the above C₁-C₆ alkyl group bonded to an oxygen atom that is also bonded to the cation ring. An alkoxyalkyl group contains an ether group bonded to an alkyl group, and here contains a total of up to six carbon atoms.

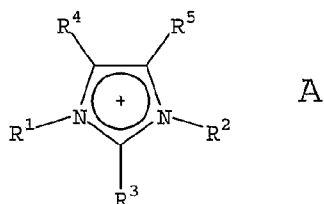
A cation that contains a single aromatic five-membered ring that is free of fusion to other ring structures is more preferred. Exemplary cations are illustrated below wherein R¹, R², and R³-R⁵, when present, are as defined before.



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Of the more preferred cations that contain a single five-membered ring free of fusion to other ring structures, an imidazolium cation that corresponds in structure to Formula A is particularly

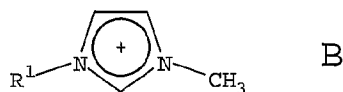
preferred, wherein R^1 , R^2 , and R^3 - R^5 , are as defined before.



5

A 1,3-di-(C_1 - C_6 -alkyl)-substituted-imidazolium or 1,3-di-(C_1 - C_6 -alkoxyalkyl)-substituted-imidazolium ion is a more particularly preferred cation; i.e., an imidazolium cation wherein R^3 - R^5 of Formula A are each hydrido, and R^1 and R^2 are independently each a C_1 - C_6 -alkyl or a C_1 - C_6 -alkoxyalkyl group. More preferably still, one of the 1,3-di- C_1 - C_6 -alkyl groups is methyl.

A 1-(C_1 - C_6 -alkyl)-3-(methyl)-imidazolium [C_n-mim, where n = 1-6] cation or a C_1 - C_6 alkoxyalkyl-3-methylimidazolium cation is more preferred, and a halogen is a preferred anion. Such a more preferred cation is illustrated by a compound that corresponds in structure to Formula B, below, wherein R^1 is a C_1 - C_6 -alkyl or a C_1 - C_6 -alkoxyalkyl group.



Most preferably, both nitrogen substituents are C_1 - C_6 -alkyl groups and one of the 1,3-di- C_1 - C_6 -alkyl groups is methyl, the other of the R^1 and the

R² C₁-C₆-alkyl groups is C₁-C₄-alkyl, and the R³-R⁵ groups are hydrido.

The phrase "when present" is often used herein in regard to substituent R group because not
5 all cations have all of the numbered groups.

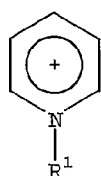
The phrases "substantial absence" and "substantially free" are used synonymously to mean that less than about 5 weight percent water is present, for example. More preferably, less than
10 about one percent water is present in the composition. The same meaning is intended regarding the presence of a nitrogen-containing base.

The anions of the ionic liquid can be hydrophilic or hydrophobic. Exemplary hydrophilic
15 anions include halogen, pseudohalogen, and C₁-C₆ carboxylate. Exemplary hydrophobic anions include tetrafluoroborate (BF₄⁻), hexafluorophosphate (PF₆⁻), polyfluoro C₂-C₆ carboxylate such as trifluoroacetate (F₃CCO₂⁻), pentafluoropropionate (F₅C₃O₂⁻),
20 bis(trifluoromethane-sulfonyl)imide (Tf₂N⁻), trifluoromethanesulfonate (Tf⁻), and the like. Hydrophobic anions that contain covalently bonded fluorine atoms are particularly preferred. Additional illustrative hydrophobic ionic liquids are
25 disclosed in U.S. Patent No. 5,827,602.

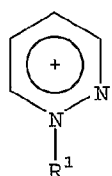
The anions commonly used include inorganic halogens and pseudohalogens (chloride, bromide, nitrate, sulfate, alkylsulfate, sulfonate), organic carboxylates (acetate, lactate), fluorinated
30 (tetrafluoroborate, hexafluorophosphate, trifluorosulfonate, trifluoroacetate, bis(trifluoromethanesulfonyl)imide,

bis(perfluoroethylsulfonyl)imide) and halometallate
(for example chloride- AlCl_3 compositions) anions.

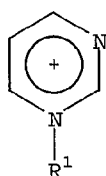
It is preferred that all R groups that are
not required for cation formation; i.e., those other
5 than R^1 and R^2 for compounds other than the
imidazolium, pyrazolium, triazolium, pyrrolidinium
and piperadinium cations shown above, be hydrido.
Thus, the cations shown above preferably have a
structure that corresponds to a structure shown
10 below, wherein R^1 and R^2 are as described before.



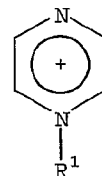
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PYRIDAZINIUM



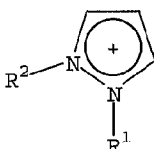
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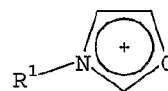
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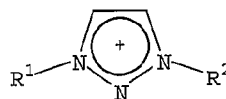
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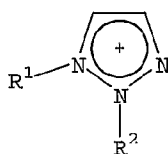
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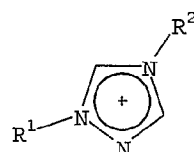
OXAZOLIUM



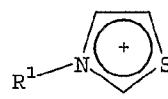
1,2,3-TRIAZOLIUM



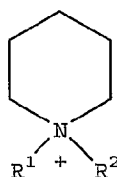
1,2,4-TRIAZOLIUM



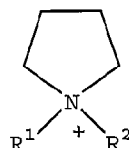
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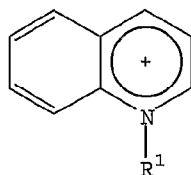
THIAZOLIUM



PIPERIDINIUM

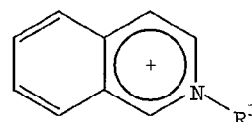


PYRROLIDINIUM



QUINOLINIUM

and



ISOQUINOLINIUM

5 A comparison of the working temperature range among an ionic liquid and some typical thermometric liquids is shown in Table 1. As shown in the table, the ionic liquid has a wide working temperature range.

10

TABLE 1

Liquid	Working Temperature
	Range, °C
Mercury	-35 to 350
Ethanol	-80 to 60
Pentane	-200 to 30
Toluene	-80 to 100
[C ₂ mim][BF ₄]	-80 to 400 ^a

^aBased on suppression of freezing point by doping with a second ionic liquid.

15

Exemplary liquification temperatures [i.e., melting points (MP) and glass transition temperatures (T_g)] and decomposition temperatures for illustrative

1,3-di-C₁-C₆-alkyl imidazolium ion-containing [(mim)]
 ionic liquids wherein one of R¹ and R² is methyl are
 shown in Table 2 below. Data for other
 representative ionic liquids containing 1-alkyl-
 5 pyridinium cations are shown in Table 3 below.

Table 2

Ionic Liquid	Liquifi- cation Temperature (°C)	Decomposition Temperature (°C)	Citation*
[C ₂ mim] Cl	64	285	a
[C ₃ mim] Cl		282	a
[C ₄ mim] Cl	41	254	b
[C ₆ mim] Cl	-69	253	g
[C ₈ mim] Cl	-73	243	g
[C ₂ mim] I		303	a
[C ₄ mim] I	-72	265	b
[C ₄ mim] [PF ₆]	10	349	b
[C ₂ mim] [PF ₆]	58-60	375	c, a
[C ₃ mim] [PF ₆]	40	335	a
[iC ₃ mim] [PF ₆]	102		a
[C ₆ mim] [PF ₆]	-61	417	d
[C ₄ mim] [BF ₄]	-81	403, 360	d, e
[C ₂ mim] [BF ₄]	6	412	a, e
[C ₂ mim] [C ₂ H ₃ O ₂]	45		c
[C ₂ mim] [C ₂ F ₃ O ₂]	14	About 150	f

10 a) Ngo et al., *Thermochim. Acta*, 2000, **357**, 97.

- b) Fannin et al., *J. Phys. Chem.*, 1984, **88**, 2614.
 c) Wilkes et al., *Chem. Commun.*, 1992, 965.
 d) Suarez et al., *J. Chim. Phys.*, 1998, **95**, 1626.
 e) Holbrey et al., *J. Chem. Soc., Dalton Trans.*,
 5 1999, 2133.
 f) Bonhôte et al., *Inorg. Chem.*, 1996, **35**, 1168.
 g) Visser et al., *Green. Chem.*, 2001, **3**, 156.

10

Table 3

Ionic Liquid	Liquification	Decomposition
	Temperature (°C)	Temperature (°C)
[1-butyl-3-methylpyridinium] [PF ₆]	37	347
[1-butyl-4-methylpyridinium] [PF ₆]	3	358
[1-hexyl-4-methylpyridinium] [PF ₆]	39	
[4-phenylpropyl-pyridinium] [PF ₆]	2	163-474
[3-n-butyl-pyridinium] [PF ₆]	0	125-444
[1-butyl-4-methylpyridinium] [BF ₄]	-24	332
[1-butyl-4-methylpyridinium] Cl	32	214
[1-hexyl-4-methylpyridinium] Cl	63	218

Not all combinations of cations and anions
 15 result in ionic liquids. Thus, in some examples,
 high melting solids can be produced, but those solids
 can be readily identified and not used. The
 systematic study of the molecular features of the
 cation and anion governing the formation of low

melting ionic liquids is the subject of active research, both to understand ionic liquid systems and to predict new examples.

Ionic liquids that melt below room
5 temperature are referred to as room temperature ionic liquids. A contemplated ionic liquid is liquid at or below a temperature of about 200°C, preferably below a temperature of about 150°C and above a temperature of about -50°C. Examples of such liquids include
10 [C₂mim]Cl/AlCl₃, [C₂mim][BF₄], [C₄mim][PF₆], and emim[NTf₂], wherein "mim" is a 1-substituted-3-methylimidazolium ion and "e" or "C₂" is 1-ethyl and C₄ is 1-butyl. More preferably, a contemplated ionic liquid is liquid (molten) at or below a temperature
15 of about 120°C and above a temperature of about -44°C. Most preferably, the ionic liquid is liquid (molten) at ambient temperature. The liquid range of these ionic liquids can be from about -72 °C to over 350 °C.

20 In the pure form, many of the ionic liquids form viscous glasses on cooling below room temperature, which can limit the lower operational temperature of a LIG containing such ionic liquid. The solidification point and viscosity of ionic
25 liquids can be reduced by admixing with one or more other ionic liquids or with another liquid material or organic solvent, producing a formulation. Such admixture has been shown, in several studies, to significantly reduce the viscosity of the admixture.

30 In evaluating individual ionic liquids or mixtures that can be used as thermometric fluids, a range of features needs to be considered: the working temperature range, the linear expansion coefficient

of the liquid over the operational temperature range, the stability of the ionic liquid, and the environmental impact of spills or breakage.

Of the known ionic liquids with published
5 rheological properties, those containing
perfluorinated anions have the lowest viscosity, and
this is often coupled to low melting points. From
this aspect, tetrafluoroborate or bistriflylimide
ionic liquids appear to offer a preferred
10 viscosity/temperature profile. However, in the pure
form, the bistriflylimide salts have well defined
crystallization points and freeze above -25 °C, which
could limit low temperature applications.

A formulation in which two or more ionic
15 liquids are mixed offers a preferred option for
reducing the solidification temperatures of the
systems by suppressing the melting/freezing point and
by decreasing viscosity. This has been demonstrated,
for example by MacFarlane and co-workers [Sun et al.,
20 *J. Phys. Chem. B*, 1998, **102**, 8858] for quaternary
ammonium systems with mixed cations in which certain
compositions suppress the melting point of the
mixture by up to 40 °C. The second ionic liquid can
itself be a colored ionic salt such as an imidazolium
25 tetrachlorometallate salt such as [C₄mim]₂[PdCl₄]
(brown) or [C₄mim]₂[NiCl₄] (blue), or the colorant
can be dissolved or dispersed in the ionic liquid.

The ionic liquid is contained within any
convenient holder. Preferably the holder is
30 partially translucent or transparent. The holder can
be composed of glass or more preferably a flexible
plastic, although other materials such as metals or
ceramics can also be used.

Although there are few data available on the toxicological and environmental effects of ionic liquids, it is believed that the effect of ionic liquids in the environment should be the sum of the
5 two (or more) component ions. The activity of some imidazolium salts has been reported as antielectrostatic and antifungal. The acute toxicity of 1-hexyloxymethyl-3-methylimidazolium tetrafluoroborate [Pernak et al., *Ind. Eng. Chem.*
10 *Res.*, 2001] has been investigated and the LD₅₀ for rats was reported as 1400 mg/kg. Cations containing short chain alkyl substituents rather than ether groups are thought to have even lower toxicity.

It should also be noted that many existing
15 ionic liquids are structurally related or comparable to known quaternary salts, for example alkylammonium, alkylpyridinium, and alkylphosphonium salts, that are widely used in industry and also in domestic environments in soaps, detergents, personal products
20 and in food packaging. From a disposal perspective, an ionic liquid that is water-soluble is more desirable than one of the classes of water-insoluble, hydrophobic ionic liquids.

It has been shown that the addition of non-
25 ionic liquid co-solvents, or solutes can have a profound effect on the physical properties of ionic liquids. Melting points and viscosity can be significantly reduced by the presence of even small concentrations (less than 5 percent) of an additive,
30 for example water, ethanol, dimethylsulfoxide, or 1-methylimidazole.

Each of the patents, applications and
articles cited herein is incorporated by reference.
The use of the article "a" or "an" is intended to
5 include one or more.

From the foregoing, it will be observed
10 that numerous modifications and variations can be
effected without departing from the true spirit and
scope of the present invention. It is to be
understood that no limitation with respect to the
specific examples presented is intended or should be
15 inferred. The disclosure is intended to cover by the
appended claims modifications as fall within the
scope of the claims.

WHAT IS CLAIMED IS:

1. A temperature sensor using a liquid,
the sensor comprising:
 - 5 a thermometer, having an elongated vessel
and a reservoir for liquid;
the thermometer further comprising a bore,
within the elongated vessel, the bore being in
liquid communication with the reservoir;
10 at least one graduation, associated with
the elongated vessel;
wherein the liquid is a thermometric ionic
liquid which rises or falls, within the bore,
depending on the temperature ambient to the
15 thermometer.
2. The temperature sensor of claim 1,
wherein the thermometer measures temperatures in a
range of about -100° to about +400° Centigrade.
20
3. The temperature sensor of claim 1,
including a plurality of graduations.
4. The temperature sensor of claim 3,
25 wherein the plurality of graduations includes a
sufficient number to express a range of temperatures
equivalent to about -100° to about +400° Centigrade.
5. The temperature sensor of claim 1,
30 wherein a contrast medium is added to the liquid such
that the level of the liquid in the bore may be more
easily seen.

6. The temperature sensor of claim 1,
wherein a colored dye is added to the liquid such
that the level of the liquid in the bore may be more
easily seen.

5

7. The temperature sensor of claim 1,
wherein the space within the bore is a vacuum.

8. The temperature sensor of claim 1,
10 wherein the volume of liquid in the bore is dependent
on temperature.

9. The temperature sensor of claim 1,
wherein the elongated vessel is created from a
15 transparent material.

10. A temperature sensor using a liquid,
the sensor comprising:

a thermometer, having an elongated vessel
20 and a reservoir for liquid;

the thermometer further comprising a bore,
within the elongated vessel, the bore being in
liquid communication with the reservoir;

a plurality of graduations associated with
25 the elongated vessel, said graduations expressing a
range of temperatures equivalent to about -100° to
about +400° Centigrade;

wherein the liquid is a thermometric ionic
liquid, which rises or falls within the bore
30 depending on the temperature ambient to the
thermometer and including a contrast medium such that
the level of the liquid in the bore can be more
easily seen; and

wherein the thermometer measures temperatures in a range of about -100° to about +400° Centigrade.

5 11. The temperature sensor of claim 10, wherein a colored dye is added to the liquid such that the level of the liquid in the bore may be more easily seen.

10 12. The temperature sensor of claim 10, wherein the space within the bore is a vacuum.

 13. The temperature sensor of claim 10, wherein the volume of liquid in the bore is dependent
15 on temperature.

 14. The temperature sensor of claim 10, wherein the elongated vessel is created from a transparent material.

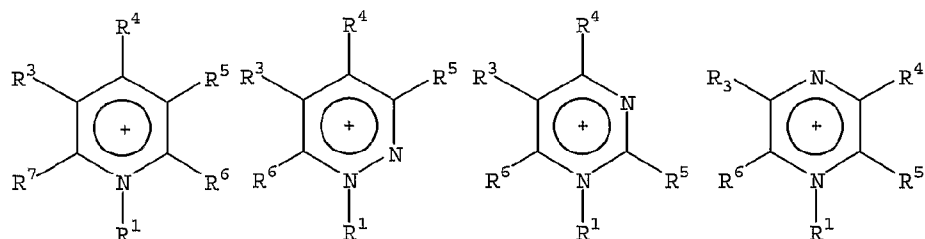
20 15. The temperature sensor of claim 1 wherein the ionic liquid is comprised of an organic cation and an organic anion or mixtures thereof.

25 16. The temperature sensor of claim 1 wherein the ionic liquid is comprised of an organic cation and an inorganic anion or mixtures thereof.

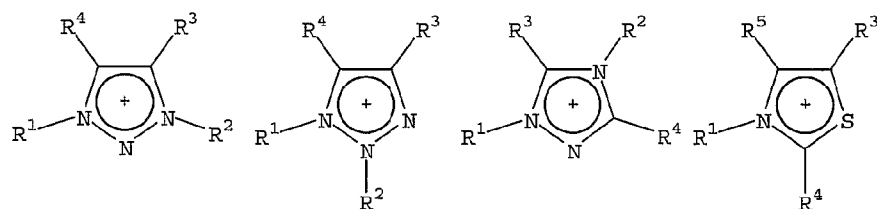
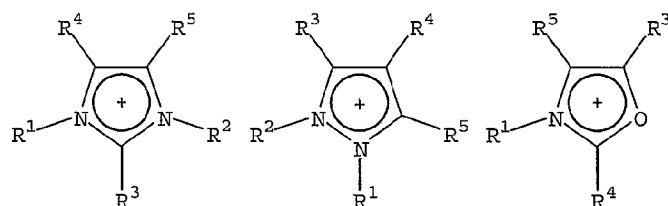
 17. The temperature sensor of claim 15
30 wherein the organic cation is selected from the group consisting of substituted pyridinium, pyridazinium, pyrimidinium, pyrazinium, pyrazolium, imidazolium, oxazolium, triazolium, thiazolium, pyrrolidinium,

piperazinium, quinolinium, isoquinolinium, ammonium, and phosphonium derivatives and mixtures thereof.

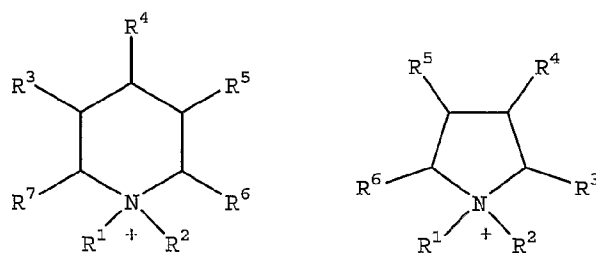
18. The temperature sensor of claim 15
 5 wherein the organic cation corresponds in structure to a formula selected from the group consisting of

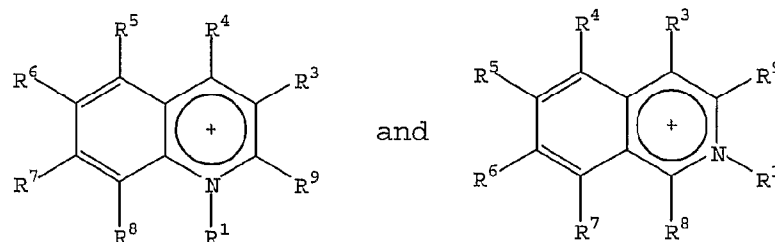


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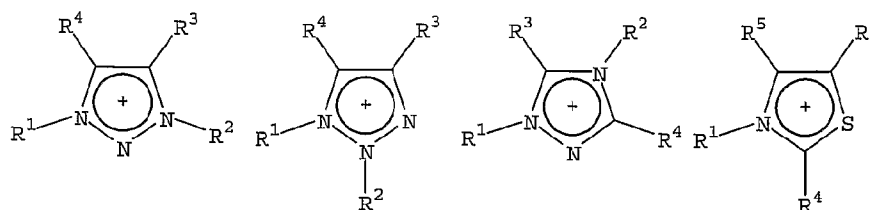


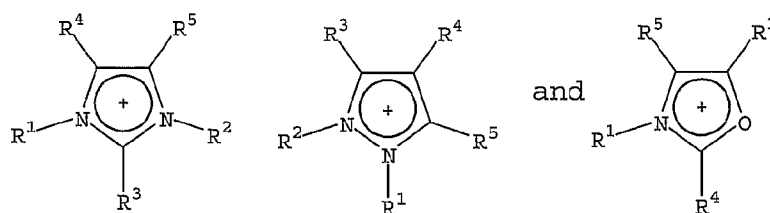


wherein R¹ and R² are independently hydrido, a C₁-C₆ alkyl group or a C₁-C₆ alkoxyalkyl group, and R³, R⁴, R⁵, R⁶, R⁷, R⁸ and R⁹ (R³-R⁹), when present, are independently a hydrido, a C₁-C₆ alkyl, a C₁-C₆ alkoxyalkyl group or a C₁-C₆ alkoxy group, and the anion is selected from the group consisting of a halogen, pseudohalogen, a C₁-C₆ carboxylate, tetrafluoroborate, hexafluorophosphate, a polyfluoro C₂-C₆ carboxylate, bis(trifluoromethanesulfonyl)imide, and trifluoromethanesulfonate.

19. The temperature sensor of claim 15 wherein the organic cation is a single, five-membered aromatic ring that is free of fusion to other ring structures.

20. The temperature sensor of claim 19 wherein the ionic liquid comprises an organic cation that corresponds in structure to a formula selected from the group consisting of





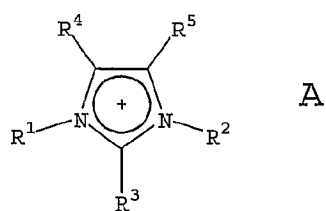
wherein R¹ and R² are independently hydrido, a C₁-C₆ alkyl group or a C₁-C₆ alkoxyalkyl group, and R³, R⁴, R⁵ (R³-R⁵) are independently a
 5 hydrido, a C₁-C₆ alkyl group, a C₁-C₆ alkoxyalkyl group or a C₁-C₆ alkoxy group.

21. The temperature sensor of claim 20 wherein the ionic liquid comprises a 1,3-di-C₁-C₆-
 10 alkyl imidazolium ion.

22. The temperature sensor of claim 21 wherein the ionic liquid comprises an organic cation with C₁-C₆ alkyl groups selected from the group
 15 consisting of methyl, ethyl, propyl, iso-propyl, butyl, sec-butyl, iso-butyl, pentyl, iso-pentyl, hexyl, 2-ethylbutyl, and 2-methylpentyl.

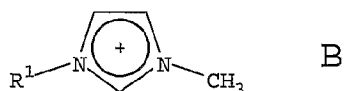
23. The temperature sensor of claim 15 wherein the organic cation is a 1-C₁-C₆-alkyl-3-methylimidazolium or a C₁-C₆ alkoxyalkyl-3-methylimidazolium cation.

24. The temperature sensor of claim 20 wherein the ionic liquid comprises an organic cation of the formula



wherein R¹ and R² are independently a C₁-C₆-alkyl group or a C₁-C₆-alkoxyalkyl group, and R³,
 5 R⁴, R⁵ (R³-R⁵) are independently a hydrido, a C₁-C₆ alkyl group, a C₁-C₆ alkoxyalkyl group or a C₁-C₆ alkoxy group.

25. The temperature sensor of claim 21
 10 wherein the ionic liquid comprises an organic cation whose structure corresponds to formula B



15 wherein R¹ is a C₁-C₆-alkyl group.

26. The temperature sensor of claim 15
 wherein the anion is selected from the group
 consisting of tetrafluoroborate, hexafluorophosphate,
 20 polyfluorocarboxylate, trifluoroacetate,
 pentafluoropropionate, bis(trifluoromethanesulfonyl)-
 imide and trifluoromethane sulfonate.

27. The temperature sensor of claim 1
 25 wherein the holder is partially transparent or translucent.

28. The temperature sensor of claim 27 wherein the holder is glass.

29. The temperature sensor of claim 5 wherein the colored
5 dye is itself an ionic liquid, an imidazolium tetrachlorometallate salt or mixtures thereof.

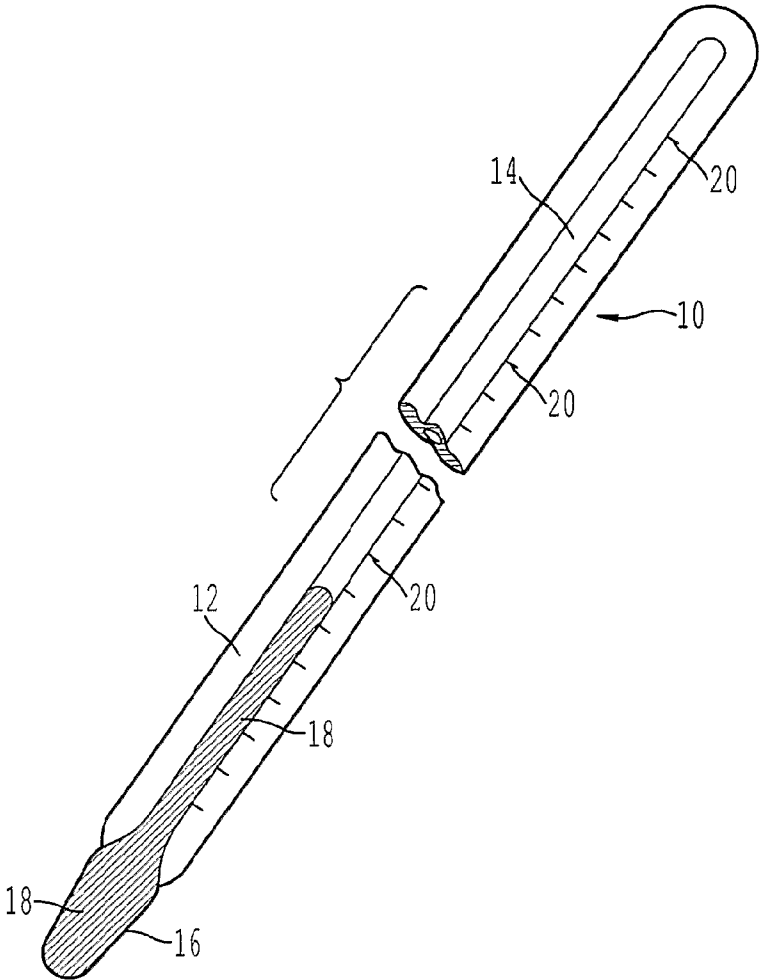


FIG. 1