# Package 'iapws'

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**Title** Formulations of the International Association for the Properties of Water and Steam

**Depends** R (>= 3.0.0)

**Description** Implementation of some of the formulations for the thermodynamic and transport properties of ordinary water and steam released by the International Association for the Properties of Water and Steam (IAPWS). More specifically, the releases referenced R1-76(2014), R6-95(2018), R7-97(2012), R8-97, R12-08 and R15-11 at <http://iapws.org>.

**License** GPL (>= 3)

**NeedsCompilation** yes

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## R topics documented:

`iapws95` *IAPWS Formulation 1995 in the Single Phase Regions*

## Description

Compute thermodynamic and transport properties of water and steam using the IAPWS formulation 1995.

## Usage

```
iapws95(what, rho, t)
iapws95_pt(what, p, t, state = iapws95_state(p, t))
```

## Arguments

| | |
|---|---|
| `what` | a character vector listing the output properties. See Details for available properties. |
| `rho` | a numeric vector giving the values of density in kg/m^3. |
| `t` | a numeric vector giving the temperature values in K. |
| `p` | a numeric vector giving the pressure values in MPa. |
| `state` | a character vector giving the physical state. One of `"liquid"`, `"gas"` or `"supercritical"`. |

## Details

The currently available properties are:

- `"f"`: the specific free energy in kJ/kg.
- `"g"`: the specific Gibbs enthalpy in kJ/kg.
- `"u"`: the specific internal energy in kJ/kg.
- `"h"`: the specific enthalpy in kJ/kg.
- `"s"`: the specific entropy in kJ/K/kg.
- `"t"`: the temperature in K.
- `"p"`: the pressure in MPa.
- `"v"`: the specific volume in $m^3$/kg.
- `"rho"`: the mass density in kg/$m^3$.
- `"cv"`: the specific isochoric heat capacity in kJ/K/kg.
- `"cp"`: the specific isobaric heat capacity in kJ/K/kg.
- `"alpha"`: the expansion coefficient in 1/K
- `"beta"`: the pressure coefficient in MPa/K.
- `"chit"`: the isothermal compressibility in 1/MPa.
- `"w"`: the speed of sound in m/s.
- `"eta"`: the dynamic viscosity in $10^{-6}$Pa.s.
- `"lambda"`: the thermal conductivity in mW/K/m.
- `"sigma"`: the surface tension in mN/m.
- `"epsilon"`: the dielectric constant.

## Value

A numeric matrix of dimension `c(n, length(what))` with `n` the maximum length of either `rho`, `p`, `t` or `state`.

## Note

Computing several properties in a single call may be more efficient than separately because most of the computation time is shared.

## Author(s)

Jonathan Debove

## References

International Association for the Properties of Water and Steam, IAPWS R6-95(2018), Revised Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use.

International Association for the Properties of Water and Steam, IAPWS R12-08(2008), Release on the IAPWS Formulation 2008 for the Viscosity of Ordinary Water Substance.

International Association for the Properties of Water and Steam, IAPWS R15-11(2011), Release on the IAPWS Formulation 2011 for the Thermal Conductivity of Ordinary Water Substance.

International Association for the Properties of Water and Steam, IAPWS R1-76(2014), Revised Release on Surface Tension of Ordinary Water Substance

International Association for the Properties of Water and Steam, IAPWS R8-97, Release on the Static Dielectric Constant of Ordinary Water Substance for Temperatures from 238 K to 873 K and Pressures up to 1000 MPa

## Examples

```
# IAPWS95 Tab. 7
tab7 <- iapws95(c("p", "cv", "w", "s"),
                t = c(300, 300, 300,
                      500, 500, 500, 500,
                      647,
                      900, 900, 900),
                rho = c(0.9965560e3, 0.1005308e4, 0.1188202e4,
                        0.4350000e0, 0.4532000e1, 0.8380250e3, 0.1084564e4,
                        0.3580000e3,
                        0.2410000e0, 0.5261500e2, 0.8707690e3))
format(tab7, scientific = TRUE, digits = 9)


# Viscosity Tab. 4
tab4 <- iapws95("eta",
                t = c(298.15, 298.15, 373.15,
                      433.15, 433.15,
                      873.15, 873.15, 873.15,
                      1173.15, 1173.15, 1173.15),
```

```
                rho = c(998, 1200, 1000,
                        1, 1000,
                        1, 100, 600,
                        1, 100, 400))
format(tab4, digits = 8)


# Viscosity Tab. 5
tab5 <- iapws95("eta", t = 647.35,
              rho = c(122, 222, 272, 322, 372, 422))
format(tab5, digits = 8)


# Thermal conductivity Tab. 4
tab4 <- iapws95("lambda",
                t = c(298.15, 298.15, 298.15, 873.15),
                rho = c(0, 998, 1200, 0))
format(tab4, digits = 9)


# Thermal conductivity Tab. 5
tab5 <- iapws95("lambda", t = 647.35,
                rho = c(1, 122, 222, 272, 322, 372, 422, 750))
format(tab5, digits = 9)


# Dielectric constant Tab. 4
tab4 <- iapws95_pt("epsilon",
                   p = c(0.1013125, 0.1013125, 10, 1000,
                         10, 100, 500, 10, 100, 500),
                   t = c(240, 300, 300, 300,
                         650, 650, 650, 870, 870, 870),
   state = c(rep("liquid", 4),
     "gas", rep("supercritical", 2),
     "gas", rep("supercritical", 2)))
format(tab4, digits = 6)
```

---

`iapws95_sat` *IAPWS Formulation 1995 in the Saturation Region*

---

## Description

Compute thermodynamic and trasport properties of water and steam along the saturated line according to the IAPWS formulation 1995.

## Usage

```
iapws95_sat(what, t)
iapws95_sat_p(what, p)
```

## Arguments

| | |
|---|---|
| what | a character vector listing the output properties. See Details for available properties. |
| t | a numeric vector giving the temperature values in K. |
| p | a numeric vector giving the pressure values in MPa. |

## Details

The currently available properties are:

- "f": the specific free energy in kJ/kg.
- "g": the specific Gibbs enthalpy in kJ/kg.
- "u": the specific internal energy in kJ/kg.
- "h": the specific enthalpy in kJ/kg.
- "s": the specific entropy in kJ/K/kg.
- "t": the temperature in K.
- "p": the pressure in MPa.
- "v": the specific volume in $m^3$/kg.
- "rho": the mass density in kg/$m^3$.
- "cv": the specific isochoric heat capacity in kJ/K/kg.
- "cp": the specific isobaric heat capacity in kJ/K/kg.
- "alpha": the expansion coefficient in 1/K
- "beta": the pressure coefficient in MPa/K.
- "chit": the isothermal compressibility in 1/MPa.
- "w": the speed of sound in m/s.
- "eta": the dynamic viscosity in $10^{-6}$Pa.s.
- "lambda": the thermal conductivity in mW/K/m.
- "sigma": the surface tension in mN/m.
- "epsilon": the dielectric constant.

## Value

A numeric array of dimension `c(n, length(what), 2L)` with `n` the length of either `p` or `t`. The last dimension indicate the physical state (`"liquid"` or `"gas"`).

## Note

Computing several properties in a single call may be more efficient than separately because most of the computation time is shared.

## Author(s)

Jonathan Debove

## References

International Association for the Properties of Water and Steam, IAPWS R6-95(2018), Revised Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use.

## Examples

```
# IAPWS95 Tab. 8
tab8 <- iapws95_sat(c("p", "rho", "h", "s"), t = c(275, 450, 625))
format(tab8, scientific = TRUE, digits = 9)
```

---

`iapws95_state` *IAPWS Formulation 1995 Physical State*

---

## Description

Compute the physical state of water according the IAPWS formulation 1995.

## Usage

```
iapws95_state(p, t)
iapws95_state_rhot(rho, t)
```

## Arguments

| | |
|---|---|
| `rho` | a numeric vector giving the values of density in kg/m^3. |
| `p` | a numeric vector giving the pressure values in MPa. |
| `t` | a numeric vector giving the temperature values in K. |

## Value

A character vector giving the physical state. One of `"solid"`, `"liquid"`, `"gas"`, `"supercritical"`, `"saturated"` or `"undef"`.

## Author(s)

Jonathan Debove

## Examples

```
iapws95_state(c(.1, .1, 23), c(293.15, 373.15, 650))
iapws95_state_rhot(c(1000, .1, 500, 500), c(293.15, 373.15, 650, 373.15))
```

`if97` *IAPWS-IF97 Basic Equations for Regions 1, 2, 3 and 5*

## Description

Compute thermodynamic and transport properties of water and steam using the IAPWS industrial formulation 1997.

## Usage

```
if97(what, p, t, state = if97_state(p, t))
```

## Arguments

| | |
|---|---|
| `what` | a character vector listing the output properties. See Details for available properties. |
| `p` | a numeric vector giving the pressure values in MPa. |
| `t` | a numeric vector giving the temperature values in K. |
| `state` | a character vector giving the physical state. One of `"liquid"`, `"gas"` or `"supercritical"`. |

## Details

The currently available properties are:

- `"f"`: the specific free energy in kJ/kg.
- `"g"`: the specific Gibbs enthalpy in kJ/kg.
- `"u"`: the specific internal energy in kJ/kg.
- `"h"`: the specific enthalpy in kJ/kg.
- `"s"`: the specific entropy in kJ/K/kg.
- `"t"`: the temperature in K.
- `"p"`: the pressure in MPa.
- `"v"`: the specific volume in $m^3$/kg.
- `"rho"`: the mass density in kg/$m^3$.
- `"cv"`: the specific isochoric heat capacity in kJ/K/kg.
- `"cp"`: the specific isobaric heat capacity in kJ/K/kg.
- `"alpha"`: the expansion coefficient in 1/K
- `"beta"`: the pressure coefficient in MPa/K.
- `"chit"`: the isothermal compressibility in 1/MPa.
- `"w"`: the speed of sound in m/s.
- `"eta"`: the dynamic viscosity in $10^{-6}$Pa.s.
- `"lambda"`: the thermal conductivity in mW/K/m.
- `"sigma"`: the surface tension in mN/m.
- `"epsilon"`: the dielectric constant.

## Value

A numeric matrix of dimension `c(n, length(what))` with `n` the maximum length of either `p`, `t` or `state`.

## Note

Computing several properties in a single call may be more efficient than separately because most of the computation time is shared.

## Author(s)

Jonathan Debove

## References

International Association for the Properties of Water and Steam, IAPWS R7-97(2012), Revised Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam.

International Association for the Properties of Water and Steam, IAPWS R12-08(2008), Release on the IAPWS Formulation 2008 for the Viscosity of Ordinary Water Substance.

International Association for the Properties of Water and Steam, IAPWS R15-11(2011), Release on the IAPWS Formulation 2011 for the Thermal Conductivity of Ordinary Water Substance.

## Examples

```
what <- c("v", "h", "u", "s", "cp", "w")

# Region 1 Tab. 5
tab5 <- if97(what, t = c(300, 300, 500), p = c(3, 80, 3))
format(tab5, scientific = TRUE, digits = 9)

# Region 2 Tab. 15
tab15 <- if97(what, t = c(300, 700, 700), p = c(3.5e-3, 3.5e-3, 30))
format(tab15, scientific = TRUE, digits = 9)

# Region 2 metastable Tab. 18
tab18 <- if97(what, t = c(450, 440, 450), p = c(1, 1, 1.5), state = "gas")
format(tab18, scientific = TRUE, digits = 9)

# Region 3 Tab. 33
tab33 <- if97(what, t = c(650, 650, 750),
              p = c(0.255837018e2, 0.222930643e2, 0.783095639e2))
format(tab33, scientific = TRUE, digits = 9)

# Region 5 Tab. 42
tab42 <- if97(what, t = c(1500, 1500, 2000), p = c(0.5, 30, 30))
format(tab42, scientific = TRUE, digits = 9)
```

```
# Viscosity and thermal conductivity
what <- c("lambda", "eta")

# Region 1 Tab. 7
tab7 <- if97(what, p = c(20, 50), t = c(620, 620))
format(tab7, scientific = TRUE, digits = 9)

# Region 2 Tab. 8
tab8 <- if97(what, p = c(0.3, 50), t = c(650, 800))
format(tab8, scientific = TRUE, digits = 9)

## Region 3 Tab. 9
#tab9 <- if97_rhot(c("lambda", "rho", "cp", "cv", "eta"),
#     rho = c(0.3, 50), t = c(222, 322)),
#format(tab9, scientific = TRUE, digits = 9)
```

---

`if97_sat` *IAPWS-IF97 Equations in Region 4*

---

## Description

Compute the pressure and the temperature along the saturated line according to the IAPWS industrial formulation 1997.

## Usage

```
if97_psat(t)
if97_tsat(p)
```

## Arguments

| | |
|---|---|
| `t` | a numeric vector giving the temperature values in K. |
| `p` | a numeric vector giving the pressure values in MPa. |

## Value

A numeric vector containing the saturation-pressure (MPa) or the saturation-temperature (K). Return `NA` for inputs outside of the range of validity.

## Author(s)

Jonathan Debove

## References

International Association for the Properties of Water and Steam, IAPWS R7-97(2012), Revised Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam.

## Examples

```
# Region 4
format(if97_psat(t = c(300, 500, 600)), scientific = TRUE, digits = 9)
format(if97_tsat(p = c(0.1, 1.0, 10.0)), scientific = TRUE, digits = 9)
```

---

`if97_state` *IAPWS-IF97 Physical State*

---

## Description

Compute the physical state of water according the IAPWS industrial formulation 1997.

## Usage

```
if97_state(p, t)
```

## Arguments

| | |
|---|---|
| `p` | a numeric vector giving the pressure values in MPa. |
| `t` | a numeric vector giving the temperature values in K. |

## Value

A character vector giving the physical state. One of `"solid"`, `"liquid"`, `"gas"`, `"supercritical"`, `"saturated"` or `"undef"`.

## Author(s)

Jonathan Debove

## Examples

```
if97_state(c(.1, .1, 23), c(293.15, 373.15, 650))
```

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