This is the APPENDIX for

An Integrated Architecture

for Engineering Problem Solving

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You can obtain the full article from <http://www.cse.unsw.edu.au/~ypisan/> or <http://www.qrg.ils.nwu.edu/> or by emailing the author at ypisan@cse.unsw.edu.au

Problem solving is an essential function of human cognition. To build intelligent systems that are capable of assisting engineers and tutoring students, we need to develop an information processing model and identify the skills used in engineering problem solving. This thesis describes the *Integrated Problem Solving Architecture (IPSA)* that combines qualitative, quantitative and diagrammatic reasoning skills to produce annotated solutions to engineering problems. We focus on representing expert knowledge, and examine how control knowledge provides the structure for using domain knowledge. To demonstrate our architecture for engineering problem solving, we present a *Thermodynamics Problem Solver (TPS)* that uses the IPSA architecture. TPS solves over 150 thermodynamics problems taken from the first four chapters of a common thermodynamics textbook and produces expert-like solutions.

Appendix

The problem statements below are reproduced here with the permission of McGraw-Hill Companies. The problem statements are taken from the first four chapters of the second edition of "Fundamentals of Engineering Thermodynamics" by John R. Howell and Richard O. Buckius, copyright 1992 by Mcgraw-Hill Companies.

2.6S Given the piston cylinder device shown in Figure 2.6S, determine the absolute pressure inside the device.

```
(add-problem :hb2.06
  :givens '((piston (at can :begin))
            (static-thermodynamic-stuff (at S :begin))
            (inside (at S :begin) (at can :begin))
            (direction (at can :begin) :down)
            (nvalue (P ATMOSPHERE) 0.1013 MPa)
            (nvalue (area (top (at can :begin))) 0.0025 m^2)
            (nvalue (acceleration GRAVITY) 9.807)
            (nvalue (Mass (at can :begin)) 30 kg))
  :goal '(find (nvalue (P (at S :begin))))
  :answer '(0.2190 MPa))


;;; Answer is correct! Given (0.219 MPA) =~ 0.218984
;;; (NVALUE (P (AT S :BEGIN)) 218984.0)
Found (WEIGHT (AT CAN :BEGIN)) = 294.21
using
    WEIGHT-OF-OBJECT
    (:= (WEIGHT (AT CAN :BEGIN)) (* (MASS (AT CAN :BEGIN))
(ACCELERATION GRAVITY)))
on
   (ACCELERATION GRAVITY) = 9.807
   (MASS (AT CAN :BEGIN)) = 30
Found (PRESSURES-ON :DOWN (TOP (AT CAN :BEGIN))) = 0
using equality
    (:= (PRESSURES-ON :DOWN (TOP (AT CAN :BEGIN))) 0)
Found (P (AT S :BEGIN)) = 218984.0
using
    PISTON-BLOCK-EQUILIBRIUM
    (:= (PRESSURES-ON :DOWN (TOP (AT CAN :BEGIN))) (- (P (AT S
:BEGIN)) (+ (/ (WEIGHT (AT CAN :BEGIN)) (AREA (TOP (AT CAN :BEGIN))))
(P ATMOSPHERE))))
on
   (PRESSURES-ON :DOWN (TOP (AT CAN :BEGIN))) = 0
   (P ATMOSPHERE) = 101300.0
   (AREA (TOP (AT CAN :BEGIN))) = 0.0025
   (WEIGHT (AT CAN :BEGIN)) = 294.21
```

```
;;; Finished <P: HB2.06>
```

2.8 If the absolute pressure inside of the piston-cylinder device shown in Figure P2.8S is 2Mpa, determine the mass of the piston.

```
(add-problem :hb2.08
  :givens '((piston (at can :begin))
            (static-thermodynamic-stuff (at s :begin))
            (inside (at s :begin) (at can :begin))
            (direction (at can :begin) :up)

            (nvalue (P (at S :begin)) 2 MPa)
            (nvalue (P ATMOSPHERE) 0.1013 MPa)
            (nvalue (area (top (at can :begin))) 1 m^2)
            (nvalue (acceleration GRAVITY) 9.807))
  :goal '(find (nvalue (mass (top (at can :begin)))))
  :answer '(193600 kg))

;;; Answer-for :HB2.08: 193606.607525237
;;; Answer is correct! Given (193600 KG) =~ 193606.607525237
;;; (NVALUE (MASS (TOP (AT CAN :BEGIN))) 193606.607525237)
Found (PRESSURES-ON :UP (TOP (AT CAN :BEGIN))) = 0
using equality
    (:= (PRESSURES-ON :UP (TOP (AT CAN :BEGIN))) 0)
Found (WEIGHT (TOP (AT CAN :BEGIN))) = 1898700.0
using
    PISTON-BLOCK-EQUILIBRIUM
    (:= (PRESSURES-ON :UP (TOP (AT CAN :BEGIN))) (- (P (AT S :BEGIN))
(+ (/ (WEIGHT (TOP (AT CAN :BEGIN))) (AREA (TOP (AT CAN :BEGIN)))) (P
ATMOSPHERE))))
on
   (PRESSURES-ON :UP (TOP (AT CAN :BEGIN))) = 0
   (P (AT S :BEGIN)) = 2000000
   (P ATMOSPHERE) = 101300.0
   (AREA (TOP (AT CAN :BEGIN))) = 1
Found (MASS (TOP (AT CAN :BEGIN))) = 193606.607525237
using
    WEIGHT-OF-OBJECT
    (:= (WEIGHT (TOP (AT CAN :BEGIN))) (* (MASS (TOP (AT CAN
:BEGIN))) (ACCELERATION GRAVITY)))
on
   (ACCELERATION GRAVITY) = 9.807
   (WEIGHT (TOP (AT CAN :BEGIN))) = 1898700.0
;;; Finished <P: HB2.08>
```

2.9S In the piston-cylinder device shown in Fig. 2.9S, determine the force necessary to produce an absolute pressure of 5 MPa within the device.

```
(add-problem :hb2.09
  :givens '((piston (at can :begin))
            (static-thermodynamic-stuff (at S :begin))
            (inside (at S :begin) (at can :begin))
```

```
            (direction (at can :begin) :left)
            (Force (at F :begin))
            (C- (forces-on :left (top (at can :begin)))
              (magnitude (at F :begin)))
            (C- (pressures-on :left (top (at can :begin)))
              (/ (magnitude (at F :begin))
                 (area (top (at can :begin)))))
            (nvalue (P (at S :begin)) 5 Mpa)
            (nvalue (P ATMOSPHERE) 0.1013 MPa)
            (nvalue (area (top (at can :begin))) 0.05 m^2)
            (nvalue (acceleration GRAVITY) 9.807)
            (nvalue (Mass (at can :begin)) 30 kg))
  :goal '(find (nvalue (magnitude (at F :begin))))
  :answer '(244.9 kN)
  )

Found (PRESSURES-ON :LEFT (TOP (AT CAN :BEGIN))) = 0
using equality
    (:= (PRESSURES-ON :LEFT (TOP (AT CAN :BEGIN))) 0)
Found (MAGNITUDE (AT F :BEGIN)) = 244935.0
using
    PISTON-BLOCK-EQUILIBRIUM
    (:= (PRESSURES-ON :LEFT (TOP (AT CAN :BEGIN))) (- (P (AT S
:BEGIN)) (+ (/ (MAGNITUDE (AT F :BEGIN)) (AREA (TOP (AT CAN
:BEGIN)))) (P ATMOSPHERE))))
on
   (PRESSURES-ON :LEFT (TOP (AT CAN :BEGIN))) = 0
   (P (AT S :BEGIN)) = 5000000
   (P ATMOSPH ERE) = 101300.0
   (AREA (TOP (AT CAN :BEGIN))) = 0.05
```

2.11S A cylinder encloses a gas with a piston as shown. The area of the piston is 0.01 m^2. Take the atmospheric pressure to be 0.101 MPa and the local gravitational acceleration as 9.8 m/s^2. If the piston supports a mass of 50 kg (including the mass of the piston), what is the gas pressure?

```
(add-problem :hb2.11
 :givens '((piston (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (nvalue (mass (top (at can :begin))) 50 kg)
           (direction (at can :begin) :up)
           (nvalue (P ATMOSPHERE) 0.101 MPa)
           (nvalue (area (top (at can :begin))) 0.001 m^2)
           (nvalue (acceleration GRAVITY) 9.8))
  :goal '(find (nvalue (P (at s :begin))))
  :answer 591000.0)


;;; Answer-for :HB2.11: 591000.0
;;; Answer is correct! Given 591000.0 =~ 591000.0
;;; (NVALUE (P (AT S :BEGIN)) 591000.0)
Found (WEIGHT (TOP (AT CAN :BEGIN))) = 490.0
using
```

```
    WEIGHT-OF-OBJECT
    (:= (WEIGHT (TOP (AT CAN :BEGIN))) (* (MASS (TOP (AT CAN
:BEGIN))) (ACCELERATION GRAVITY)))
on
   (MASS (TOP (AT CAN :BEGIN))) = 50
   (ACCELERATION GRAVITY) = 9.8
Found (PRESSURES-ON :UP (TOP (AT CAN :BEGIN))) = 0
using equality
    (:= (PRESSURES-ON :UP (TOP (AT CAN :BEGIN))) 0)
Found (P (AT S :BEGIN)) = 591000.0
using
    PISTON-BLOCK-EQUILIBRIUM
    (:= (PRESSURES-ON :UP (TOP (AT CAN :BEGIN))) (- (P (AT S :BEGIN))
(+ (/ (WEIGHT (TOP (AT CAN :BEGIN))) (AREA (TOP (AT CAN :BEGIN)))) (P
ATMOSPHERE))))
on
   (PRESSURES-ON :UP (TOP (AT CAN :BEGIN))) = 0
   (P ATMOSPHERE) = 101000.0
   (AREA (TOP (AT CAN :BEGIN))) = 0.001
   (WEIGHT (TOP (AT CAN :BEGIN))) = 490.0
;;; Finished <P: HB2.11>
```

2.13E The 100-lbm piston shown in Fig. P2.13E is free to move in the vertical cylinder and has a diameter of 5 in. If atmospheric pressure is equal to 14.7 psia and the acceleration due to gravity is 32.2 ft/s^2, determine the absolute pressure of the H_20.

```
(add-problem :hb2.13
  :givens '((piston (at can :begin))
            (static-thermodynamic-stuff (at S :begin))
            (inside (at S :begin) (at can :begin))
            (substance-of (at s :begin) water)
            (circle (top (at Can :begin)))
            (direction (at can :begin) :up)
            (nvalue (mass (top (at can :begin))) 100 lbm)
            (nvalue (diameter (top (at can :begin))) 5 in)
            (nvalue (P ATMOSPHERE) 14.7 Psi)
            (nvalue (acceleration GRAVITY) 32.2 ft/s^2))
   :goal '(find (nvalue (P (at S :begin))))
   :answer '(19.8 Psi)

;;; Answer-for :HB2.13: 136497.185066907
;;; Answer is correct! Given (19.8 PSI) =~ 19.7971203032585
;;; (NVALUE (P (AT S :BEGIN)) 136497.185066907)
Found (RADIUS (TOP (AT CAN :BEGIN))) = 0.0635
using equality
    (:= (RADIUS (TOP (AT CAN :BEGIN))) (* 0.5 (DIAMETER (TOP (AT CAN
:BEGIN)))))
Found (AREA (TOP (AT CAN :BEGIN))) = 0.0126676869774374
using equality
    (:= (AREA (TOP (AT CAN :BEGIN))) (* PI (RADIUS (TOP (AT CAN
:BEGIN))) (RADIUS (TOP (AT CAN :BEGIN)))))
Found (WEIGHT (TOP (AT CAN :BEGIN))) = 445.1884416
using
```

```
    WEIGHT-OF-OBJECT
    (:= (WEIGHT (TOP (AT CAN :BEGIN))) (* (MASS (TOP (AT CAN
:BEGIN))) (ACCELERATION GRAVITY)))
on
   (MASS (TOP (AT CAN :BEGIN))) = 1134/25
   (ACCELERATION GRAVITY) = 9.81456
Found (PRESSURES-ON :UP (TOP (AT CAN :BEGIN))) = 0
using equality
    (:= (PRESSURES-ON :UP (TOP (AT CAN :BEGIN))) 0)
Found (P (AT S :BEGIN)) = 136497.185066907
using
    PISTON-BLOCK-EQUILIBRIUM
    (:= (PRESSURES-ON :UP (TOP (AT CAN :BEGIN))) (- (P (AT S :BEGIN))
(+ (/ (WEIGHT (TOP (AT CAN :BEGIN))) (AREA (TOP (AT CAN :BEGIN)))) (P
ATMOSPHERE))))
on
   (PRESSURES-ON :UP (TOP (AT CAN :BEGIN))) = 0
   (P ATMOSPHERE) = 101353.56
   (WEIGHT (TOP (AT CAN :BEGIN))) = 445.1884416
   (AREA (TOP (AT CAN :BEGIN))) = 0.0126676869774374
;;; Finished <P: HB2.13>
```

2.15S A cylindrical tank 1.25 m long and 0.40 m in diameter contains 750 g of H_20. Calculate the specific volume and density of the H_20.

```
(add-problem :hb2.15
  :givens '((container (at can :begin))
            (circular-cylinder (at can :begin))
            (closed (at can :begin))
            (nvalue (height (at can :begin)) 1.25)
            (nvalue (diameter (top (at can :begin))) 0.40)
            (static-thermodynamic-stuff (at S :begin))
            (inside (at S :begin) (at can :begin))
            (substance-of (at s :begin) water)
            (nvalue (mass (at s :begin)) 750 g)
            (:not (liquid (at S :begin)))
            (static (at s :begin))
            (consider (geometric-properties (at s :begin))))
  :goal '(find (nvalue (density (at s :begin))))
  :answer '(4.775 kg/m^3))


;;; Answer-for :HB2.15: 4.77464829275686
;;; Answer is correct! Given (4.775 KG/M^3) =~ 4.77464829275686
;;; (NVALUE (DENSITY (AT S :BEGIN)) 4.77464829275686)
Found (RADIUS (TOP (AT CAN :BEGIN))) = 0.2
using equality
    (:= (RADIUS (TOP (AT CAN :BEGIN))) (* 0.5 (DIAMETER (TOP (AT CAN
:BEGIN)))))
Found (AREA (TOP (AT CAN :BEGIN))) = 0.125663706143592
using equality
    (:= (AREA (TOP (AT CAN :BEGIN))) (* PI (RADIUS (TOP (AT CAN
:BEGIN))) (RADIUS (TOP (AT CAN :BEGIN)))))
Found (V (AT CAN :BEGIN)) = 0.15707963267949
```

```
using
    V-OF-CYLINDER
    (:= (V (AT CAN :BEGIN)) (* (AREA (TOP (AT CAN :BEGIN))) (HEIGHT
(AT CAN :BEGIN))))
on
   (HEIGHT (AT CAN :BEGIN)) = 1.25
   (AREA (TOP (AT CAN :BEGIN))) = 0.125663706143592
Found (V (AT S :BEGIN)) = 0.15707963267949
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT S :BEGIN)))
Found (DENSITY (AT S :BEGIN)) = 4.77464829275686
using
    DENSITY-DEFINITION
    (:= (DENSITY (AT S :BEGIN)) (/ (MASS (AT S :BEGIN)) (V (AT S
:BEGIN))))
on
   (MASS (AT S :BEGIN)) = 3/4
   (V (AT S :BEGIN)) = 0.15707963267949
;;; Finished <P: HB2.15>
```

2.17E A frictionless piston-cylinder device has a cross-sectional area of 15 in^2. Find the piston mass such that the absolute pressure in the cylinder is 150 psia. Atmospheric pressure is 14.7psia, and the local acceleration of gravity is32.2 ft/s^2.

```
(add-problem :hb2.17
  :givens '((piston (at can :begin))
            (static-thermodynamic-stuff (at S :begin))
            (inside (at S :begin) (at can :begin))
            (direction (at can :begin) :up)
            (nvalue (area (top (at can :begin))) 15 in^2)
            (nvalue (P (at s :begin)) 150 psi)
            (nvalue (P ATMOSPHERE) 14.7 psi)
            (nvalue (acceleration GRAVITY) 32.2 ft/s^2))
  :goal '(find (nvalue (mass (top (at can :begin)))))
  :answer '(2026 lbm))


;;; Answer is correct! Given (2026 LBM) =~ 2027.84278361103
;;; (NVALUE (MASS (TOP (AT CAN :BEGIN))) 919.829486645963)
Found (PRESSURES-ON :UP (TOP (AT CAN :BEGIN))) = 0
using equality
    (:= (PRESSURES-ON :UP (TOP (AT CAN :BEGIN))) 0)
Found (WEIGHT (TOP (AT CAN :BEGIN))) = 9027.721686456
using
    PISTON-BLOCK-EQUILIBRIUM
    (:= (PRESSURES-ON :UP (TOP (AT CAN :BEGIN))) (- (P (AT S :BEGIN))
(+ (/ (WEIGHT (TOP (AT CAN :BEGIN))) (AREA (TOP (AT CAN :BEGIN)))) (P
ATMOSPHERE))))
on
   (PRESSURES-ON :UP (TOP (AT CAN :BEGIN))) = 0
   (AREA (TOP (AT CAN :BEGIN))) = 48387/5000000
   (P (AT S :BEGIN)) = 1034220
   (P ATMOSPHERE) = 101353.56
```

```
Found (MASS (TOP (AT CAN :BEGIN))) = 919.829486645963
using
    WEIGHT-OF-OBJECT
    (:= (WEIGHT (TOP (AT CAN :BEGIN))) (* (MASS (TOP (AT CAN
:BEGIN))) (ACCELERATION GRAVITY)))
on
   (ACCELERATION GRAVITY) = 9.81456
   (WEIGHT (TOP (AT CAN :BEGIN))) = 9027.721686456
;;; Finished <P: HB2.17>
```

2.21E Some 10 lbm of H_20 is contained in the piston-cylinder device shown in Fig. 2.21E. The initial volume enclosed is 150 in^3. If the piston rises, causing the total volume to double, calculate the final specific volume of H_20.

```
(add-problem :hb2.21
  :givens '((piston (at can :begin))
            (static-thermodynamic-stuff (at S :begin))
            (inside (at S :begin) (at can :begin))
            (direction (at can :begin) :up)
            (substance-of (At s :begin) water)
            (nvalue (mass (at S :begin)) 10 lbm)
            (nvalue (V (at can :begin)) 150 in^3)
            (heating piston-rises (At S :begin) (At S :end))
            (:not (liquid (at S :end)))
            (closed (at can :end))
            ;; piston rises doubling volume!
            (nvalue (V (at can :end)) 300 in^3))
    :goal '(find (nvalue (spec-v (at S :end))))
    :answer '(0.0174 ft^3/lbm))


;;; Answer-for :HB2.21: 2048383/1890000000
;;; Answer is correct! Given (0.0174 FT^3/LBM) =~ 5/288
;;; (NVALUE (SPEC-V (AT S :END)) 2048383/1890000000)
Found (MASS-BEGIN PISTON-RISES) = 567/125
using equality
    (:= (MASS-BEGIN PISTON-RISES) (MASS (AT S :BEGIN)))
Found (MASS-END PISTON-RISES) = 567/125
using
    CONSERVATION-OF-MASS
    (:= (+ (MASS-BEGIN PISTON-RISES) (MASS-INLET PISTON-RISES)) (+
(MASS-END PISTON-RISES) (MASS-OUTLET PISTON-RISES)))
on
   (MASS-BEGIN PISTON-RISES) = 567/125
   (MASS-OUTLET PISTON-RISES) = 0
   (MASS-INLET PISTON-RISES) = 0
Found (MASS (AT S :END)) = 567/125
using equality
    (:= (MASS-END PISTON-RISES) (MASS (AT S :END)))
Found (V (AT S :END)) = 6145149/1250000000
using equality
    (:= (V (AT CAN :END)) (V (AT S :END)))
Found (SPEC-V (AT S :END)) = 2048383/1890000000
using
```

```
    SPEC-V-DEFINITION
    (:= (SPEC-V (AT S :END)) (/ (V (AT S :END)) (MASS (AT S :END))))
on
   (V (AT S :END)) = 6145149/1250000000
   (MASS (AT S :END)) = 567/125
;;; Finished <P: HB2.21>
```

2.53S A colleague reports that she has developed a new material which will withstand an absolute temperature 3 times as great as her previous best material, which could endure a temperature of 1200 K. What is this new upper limit in kelvins and degrees Celsius?

```
(add-problem-description :hb2.53
 :givens '((basic-thermodynamic-stuff old-material)
           (nvalue (T old-material) 1200 Kelvin)
           (basic-thermodynamic-stuff new-material)
           (given-equation 3-times
            (:= (T new-material) (* 3 (T old-material))))))


(add-problem-goal :hb2.53a
  :description :hb2.53
  :goal '(find (nvalue (T new-material)))
  :answer '(3600 Kelvin))

(add-problem-goal :hb2.53b
  :description :hb2.53
  :goal '(find (nvalue (T new-material)))
  :answer '(3327 C))

;;; Answer-for :HB2.53A: 3600
;;; Answer is correct! Given (3600 KELVIN) =~ 3600
;;; (NVALUE (T NEW-MATERIAL) 3600)
Found (T NEW-MATERIAL) = 3600
using equality
    (:= (T NEW-MATERIAL) (* 3 (T OLD-MATERIAL)))
;;; Finished <P: HB2.53A>

;;; Answer-for :HB2.53B: 3600
;;; Answer is correct! Given (3327 C) =~ 3326.85
;;; (NVALUE (T NEW-MATERIAL) 3600)
Found (T NEW-MATERIAL) = 3600
using equality
    (:= (T NEW-MATERIAL) (* 3 (T OLD-MATERIAL)))
;;; Finished <P: HB2.53B>
```

2.55S A mass of 2 kg is moving at a speed of 3 m/s at a height 10 m above a reference plane. What are the values of the kinetic and potential energy of the mass, and what is the weight of the mass?

```
(add-problem-description :hb2.55
 :givens '((static-thermodynamic-stuff flying-bike)
           (complex-thermodynamic-stuff flying-bike)
```

```
           (nvalue (height flying-bike) 10 m)
           (nvalue (velocity flying-bike) 3 m/s)
           (nvalue (mass flying-bike) 2 kg)))

(add-problem-goal :hb2.55a
  :description :hb2.55
  :goal '(find (nvalue (kinetic-energy flying-bike)))
  :answer '(9 J))

(add-problem-goal :hb2.55b
  :description :hb2.55
  :goal '(find (nvalue (potential-energy flying-bike)))
  :answer '(196 J))

(add-problem-goal :hb2.55c
  :description :hb2.55
  :goal '(find (nvalue (weight flying-bike)))
  :answer '(19.6 Newton))


;;; Answer is correct! Given (9 J) =~ 9
;;; (NVALUE (KINETIC-ENERGY FLYING-BIKE) 9)
Found (KINETIC-ENERGY FLYING-BIKE) = 9
using
    KE-DEFINITION
    (:= (KINETIC-ENERGY FLYING-BIKE) (/ (* (MASS FLYING-BIKE) (SQR
(VELOCITY FLYING-BIKE))) 2))
on
   (VELOCITY FLYING-BIKE) = 3
   (MASS FLYING-BIKE) = 2
;;; Finished <P: HB2.55A>


;;; Answer-for :HB2.55B: 196.14
;;; Answer is correct! Given (196 J) =~ 196.14
;;; (NVALUE (POTENTIAL-ENERGY FLYING-BIKE) 196.14)
Found (POTENTIAL-ENERGY FLYING-BIKE) = 196.14
using
    PE-DEFINITION
    (:= (POTENTIAL-ENERGY FLYING-BIKE) (* (MASS FLYING-BIKE)
(ACCELERATION GRAVITY) (HEIGHT FLYING-BIKE)))
on
   (HEIGHT FLYING-BIKE) = 10
   (MASS FLYING-BIKE) = 2
   (ACCELERATION GRAVITY) = 9.807
;;; Finished <P: HB2.55B>


;;; Answer-for :HB2.55C: 19.614
;;; Answer is correct! Given (19.6 NEWTON) =~ 19.614
;;; (NVALUE (WEIGHT FLYING-BIKE) 19.614)
Found (WEIGHT FLYING-BIKE) = 19.614
using
    MAGNITUDE-OF-STUFF-WEIGHT
    (:= (WEIGHT FLYING-BIKE) (* (MASS FLYING-BIKE) (ACCELERATION
GRAVITY)))
```

```
on
   (MASS FLYING-BIKE) = 2
   (ACCELERATION GRAVITY) = 9.807
;;; Finished <P: HB2.55C>
```

2.57S The 10 g of water in the piston-cylinder device shown undergoes a constant-pressure process. The initial pressure is 1.0 MPa, and the initial volume is 2000 cm^3. If the final volume is 10 cm^3, find the work done. Is the work done on or by the system?

```
(add-problem :hb2.57
  :givens '((piston (at can :begin))
            (static-thermodynamic-stuff (at S :begin))
            (inside (at S :begin) (at can :begin))
            (direction (at can :begin) :up)
            (nvalue (mass (at S :begin)) 10 g)
            (nvalue (P (at S :begin)) 1 MPa)
            (nvalue (V (at S :begin)) 2000 cm^3)
            (contained-process mystery (at S :begin) (at S :end))
            (isobaric mystery)
            (nvalue (V (at S :end)) 10 cm^3))
  :goal '(find (nvalue (work mystery)))
  :answer '(-1.99 kJ))


;;; Answer-for :HB2.57: -1990
;;; Answer is correct! Given (-1.99 KJ) =~ -199/100
;;; (NVALUE (WORK MYSTERY) -1990)
Found (WORK MYSTERY) = -1990
using
    WORK=PDV-ISOBARIC
    (:= (WORK MYSTERY) (* (P (AT S :BEGIN)) (- (V (AT S :END)) (V (AT
S :BEGIN)))))
on
   (P (AT S :BEGIN)) = 1000000
   (V (AT S :BEGIN)) = 1/500
   (V (AT S :END)) = 1/100000
;;; Finished <P: HB2.57>
```

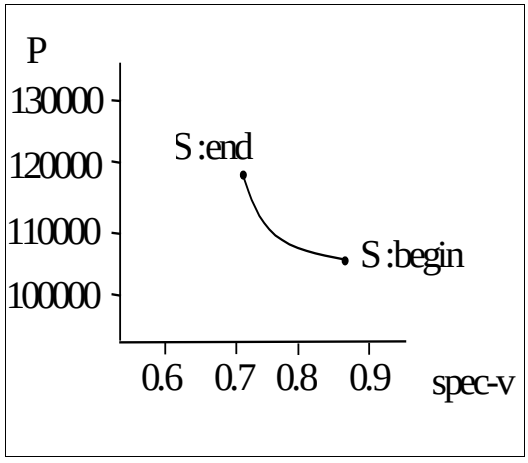
2.61 Air with mass of 1 kg and initially at P = 101.3 kPa and T = 300 K is contained within a cylinder as shown in Fig. P2.61. The cup on top of the piston is then filled at a constant rate until it contains 50 kg of water, thus compressing the gas. The compression proceeds slowly, so that heat transfer to the surroundings maintains the temperature of the air at 300 K. Assume air is an ideal gas.

(*a*) Draw a *P*-*V* diagram of the process. Label the initial state *A* and the final state *B*.

(*b*) Calculate the work done on the gas during the process.

```
(add-problem-description :hb2.61
  :givens '((piston (at can :begin))
            (static-thermodynamic-stuff (at S :begin))
            (inside (at S :begin) (at can :begin))
            (direction (at can :begin) :up)
            (substance-of (at s :begin) air)
            (nvalue (P ATMOSPHERE) 101.3 kPa)
            (nvalue (P (at S :begin)) 101.3 kPa)
            (nvalue (T (at S :begin)) 300 K)
            (nvalue (mass (at s :begin)) 1 kg)
            (contained-process mystery (at s :begin) (at s :end))
            (isothermal mystery)
            (circle (top (at can :begin)))
            (nvalue (diameter (top (at can :begin))) 0.2 m)
            ;; the cup is filled till 50kg of water in it
            (force (at F :begin))
            (acting-on (at F :end) (at can :end))
            (direction (at F :end) :down)
            (nvalue (magnitude (at F :end)) 490 Newton)))

(add-problem-goal :hb2.61a
  :description :hb2.61
  :goal '(find (nvalue (work mystery)))
  :answer '(-12.28 kJ))


(add-problem-goal :hb2.61b
  :description :hb2.61
  :goal '(plot-graph (P V) mystery))

;;; Answer-for :HB2.61A: -12372.4301061879
;;; Answer is correct! Given (-12.28 KJ) =~ -12.3724301061879
;;; (NVALUE (WORK MYSTERY) -12372.4301061879)
Found (RADIUS (TOP (AT CAN :END))) = 0.1
using equality
    (:= (RADIUS (TOP (AT CAN :END))) (* 0.5 (DIAMETER (TOP (AT CAN
:END)))))
Found (AREA (TOP (AT CAN :END))) = 0.0314159265358979
using equality
    (:= (AREA (TOP (AT CAN :END))) (* PI (RADIUS (TOP (AT CAN :END)))
(RADIUS (TOP (AT CAN :END)))))
Found (PRESSURES-ON :UP (TOP (AT CAN :END))) = 0
using equality
    (:= (PRESSURES-ON :UP (TOP (AT CAN :END))) 0)
Found (P (AT S :END)) = 116897.184423006
using
    PISTON-BLOCK-EQUILIBRIUM
    (:= (PRESSURES-ON :UP (TOP (AT CAN :END))) (- (+ (/ (MAGNITUDE
(AT F :END)) (AREA (TOP (AT CAN :END)))) (P (AT S :END))) (+ (/
(WEIGHT (TOP (AT CAN :END))) (AREA (TOP (AT CAN :END)))) (P
ATMOSPHERE))))
on
   (P ATMOSPHERE) = 101300.0
   (WEIGHT (TOP (AT CAN :END))) = 0
   (PRESSURES-ON :UP (TOP (AT CAN :END))) = 0
```

```
   (MAGNITUDE (AT F :END)) = -490
   (AREA (TOP (AT CAN :END))) = 0.0314159265358979
Found (V (AT S :BEGIN)) = 0.84995064165844
using
    IDEAL-GAS-LAW
    (:= (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (* (MASS (AT S
:BEGIN)) (R AIR) (T (AT S :BEGIN))))
on
   (P (AT S :BEGIN)) = 101300.0
   (T (AT S :BEGIN)) = 300
   (MASS (AT S :BEGIN)) = 1
   (R AIR) = 287
Found (T (AT S :END)) = 300
using equality
    (:= (T (AT S :BEGIN)) (T (AT S :END)))
Found (V (AT S :END)) = 0.736544686041687
using
    PV/T=P2V2/T2
    (:= (/ (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (T (AT S :BEGIN)))
(/ (* (P (AT S :END)) (V (AT S :END))) (T (AT S :END))))
on
   (P (AT S :BEGIN)) = 101300.0
   (T (AT S :BEGIN)) = 300
   (T (AT S :END)) = 300
   (V (AT S :BEGIN)) = 0.84995064165844
   (P (AT S :END)) = 116897.184423006
Found (WORK MYSTERY) = -12372.4301061879
using
    WORK=PDV-LINEAR
    (:= (WORK MYSTERY) (* (* (+ (P (AT S :BEGIN)) (P (AT S :END)))
0.5) (- (V (AT S :END)) (V (AT S :BEGIN)))))
on
   (P (AT S :BEGIN)) = 101300.0
   (V (AT S :BEGIN)) = 0.84995064165844
   (P (AT S :END)) = 116897.184423006
   (V (AT S :END)) = 0.736544686041687
NIL
```



3.1S Find P_1/P_2 for the states $v_1 =$ 50 m^3/kg, $T_1 = 500^\circ$C and $v_2 =$ 10 m^3/kg, $T_2 =$

1200˚C for ethane, using (*a*) the ideal gas relation, (*b*) the van der Waals equation, (*c*) the Benedict-Webb-Rubin equation, (*d*) the compressibility factor charts.

```
(add-problem-description :hb3.01
 :givens '((static-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) ethane)
           (nvalue (spec-v (at S :begin)) 50 m^3/kg)
           (nvalue (T (at S :begin)) 500 C)
           (heating heat (at S :begin) (at S :end))
           (nvalue (spec-v (at S :end)) 10 m^3/kg)
           (nvalue (T (at S :end)) 1200 C)
           (given-equation pr
             (:= (pr heat) (/ (p (at S :begin))
                              (p (at S :end)))))))


(add-problem-goal :hb3.01a
  :description :hb3.01
  :extras '((ideal-gas (at S :begin))
            (ideal-gas (at S :end)))
  :goal '(find (nvalue (pr heat)))
  :answer '(0.105))

(add-problem-goal :hb3.01b
  :description :hb3.01
  :extras '((use-van-deer-waals-equation (at S :begin))
            (use-van-deer-waals-equation (at S :end)))
  :goal '(find (nvalue (pr heat)))
  :answer '(0.105))


Found (P (AT S :BEGIN)) = 4.2755195
using
    IDEAL-GAS-SPEC-VOLUME
    (:= (* (P (AT S :BEGIN)) (SPEC-V (AT S :BEGIN))) (* (R ETHANE) (T
(AT S :BEGIN))))
on
   (SPEC-V (AT S :BEGIN)) = 50
   (T (AT S :BEGIN)) = 773.15
   (R ETHANE) = 0.2765
Found (P (AT S :END)) = 40.7325975
using
    PSPEC-V/T=P2SPEC-V2/T2
    (:= (/ (* (P (AT S :BEGIN)) (SPEC-V (AT S :BEGIN))) (T (AT S
:BEGIN))) (/ (* (P (AT S :END)) (SPEC-V (AT S :END))) (T (AT S
:END))))
on
   (SPEC-V (AT S :BEGIN)) = 50
   (T (AT S :BEGIN)) = 773.15
   (SPEC-V (AT S :END)) = 10
   (T (AT S :END)) = 1473.15
   (P (AT S :BEGIN)) = 4.2755195
Found (PR HEAT) = 0.104965550011879
using
```

```
    PR
    (:= (PR HEAT) (/ (P (AT S :BEGIN)) (P (AT S :END))))
on
   (P (AT S :BEGIN)) = 4.2755195
   (P (AT S :END)) = 40.7325975


Found (VAN-DER-WAALS-A ETHANE) = 6.1644211935025E-4
using
    VAN-DER-WAALS-EQUATION-A
    (:= (VAN-DER-WAALS-A ETHANE) (/ (* 27 (R ETHANE) (R ETHANE) (T-
CRITICAL ETHANE) (T-CRITICAL ETHANE)) (* 64 (P-CRITICAL ETHANE))))
on
   (P-CRITICAL ETHANE) = 4880000
   (T-CRITICAL ETHANE) = 305.4
   (R ETHANE) = 0.2765
Found (VAN-DER-WAALS-B ETHANE) = 2.16298924180328E-6
using
    VAN-DER-WAALS-EQUATION-B
    (:= (VAN-DER-WAALS-B ETHANE) (/ (* (R ETHANE) (T-CRITICAL
ETHANE)) (* 8 (P-CRITICAL ETHANE))))
on
   (P-CRITICAL ETHANE) = 4880000
   (T-CRITICAL ETHANE) = 305.4
   (R ETHANE) = 0.2765
Found (P (AT S :END)) = 40.7326001459977
using
    VAN-DER-WAALS-EQUATION
    (:= (P (AT S :END)) (- (/ (* (R ETHANE) (T (AT S :END))) (-
(SPEC-V (AT S :END)) (VAN-DER-WAALS-B ETHANE))) (/ (VAN-DER-WAALS-A
ETHANE) (* (SPEC-V (AT S :END)) (SPEC-V (AT S :END))))))
on
   (SPEC-V (AT S :END)) = 10
   (T (AT S :END)) = 1473.15
   (R ETHANE) = 0.2765
   (VAN-DER-WAALS-B ETHANE) = 2.16298924180328E-6
   (VAN-DER-WAALS-A ETHANE) = 6.1644211935025E-4
Found (P (AT S :BEGIN)) = 4.27551943838121
using
    VAN-DER-WAALS-EQUATION
    (:= (P (AT S :BEGIN)) (- (/ (* (R ETHANE) (T (AT S :BEGIN))) (-
(SPEC-V (AT S :BEGIN)) (VAN-DER-WAALS-B ETHANE))) (/ (VAN-DER-WAALS-A
ETHANE) (* (SPEC-V (AT S :BEGIN)) (SPEC-V (AT S :BEGIN))))))
on
   (SPEC-V (AT S :BEGIN)) = 50
   (T (AT S :BEGIN)) = 773.15
   (R ETHANE) = 0.2765
   (VAN-DER-WAALS-B ETHANE) = 2.16298924180328E-6
   (VAN-DER-WAALS-A ETHANE) = 6.1644211935025E-4
Found (PR HEAT) = 0.104965541680533
using
    PR
    (:= (PR HEAT) (/ (P (AT S :BEGIN)) (P (AT S :END))))
on
   (P (AT S :BEGIN)) = 4.27551943838121
   (P (AT S :END)) = 40.7326001459977
```

3.3S Determine whether the following processes for the specified gas can be treated as ideal gas processes. If the process is an ideal gas process, then evaluate u_2 - u_2 and h_2 - h_1, assuming constant specific heats.

(a) Isothermal process (T = constant) for water from 1200 K and 2 MPa to 10 MPa

(b) Isometric process (v = constant) for refrigerant 12 from 405 K and 4.0 MPa to 470 K

(c) Isobaric process (P = constant) for nitrogen from 250 K and 17.O MPa to 28OK

```
(add-problem-description :hb3.03
 :givens '((contained-process mystery (at s :begin) (at s :end))
           (:NOT (use-superheated-tables (at S :begin)))
           (:NOT (use-superheated-tables (at S :end)))
           (given-equation delta-spec-h
             (:= (delta-spec-h s)
              (- (spec-h (at s :end))
                 (spec-h (at s :begin)))))
           (given-equation delta-spec-u
             (:= (delta-spec-u s)
              (- (spec-u (at s :end))
                 (spec-u (at s :begin))))))))

(add-problem-goal :hb3.03a1
  :description :hb3.03
  :extras '((isothermal mystery)
            (substance-of (at S :begin) water)
            (nvalue (T (at S :begin)) 1200 K)
            (nvalue (P (at S :begin)) 2 MPa)
            (nvalue (P (at S :end)) 10 MPa))
  :goal '(find (nvalue (delta-spec-u S)))
  :answer '(0 kJ/kg))

(add-problem-goal :hb3.03a2
  :description :hb3.03
  :extras '((isothermal mystery)
            (substance-of (at S :begin) water)
            (nvalue (T (at S :begin)) 1200 K)
            (nvalue (P (at S :begin)) 2 MPa)
            (nvalue (P (at S :end)) 10 MPa))
  :goal '(find (nvalue (delta-spec-h S)))
  :answer '(0 kJ/kg))

(add-problem-goal :hb3.03b
  :description :hb3.03
  :extras '((isochoric mystery)
            (substance-of (at S :begin) refrigerant-12)
```

```
            (:not (ideal-gas-substance refrigerant-12))
            (nvalue (T (at S :begin)) 405 K)
            (nvalue (P (at S :begin)) 4 MPa)
            (nvalue (T (at S :end)) 470 K))
  :goal '(find (phase-of (at S :end)))
  :answer '((:not (ideal-gas (at s :end)))))

(add-problem-goal :hb3.03c1
  :description :hb3.03
  :extras '((isobaric mystery)
            (substance-of (at S :begin) nitrogen)
            (nvalue (T (at S :begin)) 250 K)
            (nvalue (P (at S :begin)) 1.7 MPa)
            (nvalue (T (at S :end)) 280 K))
  :goal '(find (nvalue (delta-spec-u S)))
  :answer '(22.3 kJ/kg))

(add-problem-goal :hb3.03c2
  :description :hb3.03
  :extras '((isochoric mystery)
            (substance-of (at S :begin) NITROGEN)
            (nvalue (T (at S :begin)) 250 K)
            (nvalue (P (at S :begin)) 1.7 MPa)
            (nvalue (T (at S :end)) 280 K))
  :goal '(find (nvalue (delta-spec-h S)))
  :answer '(31.23 kJ/kg))

;;; Answer-for :HB3.03A1: 0.0
;;; Answer is correct! Given (0 KJ/KG) =~ 0.0
;;; (NVALUE (DELTA-SPEC-U S) 0.0)
Found (SPEC-U (AT S :BEGIN)) = 1683720.0
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :BEGIN)) (* (CV WATER) (T (AT S :BEGIN))))
on
   (T (AT S :BEGIN)) = 1200
   (CV WATER) = 1403.1
Found (T (AT S :END)) = 1200
using equality
    (:= (T (AT S :BEGIN)) (T (AT S :END)))
Found (SPEC-U (AT S :END)) = 1683720.0
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :END)) (* (CV WATER) (T (AT S :END))))
on
   (T (AT S :END)) = 1200
   (CV WATER) = 1403.1
Found (DELTA-SPEC-U S) = 0.0
using
    DELTA-SPEC-U
    (:= (DELTA-SPEC-U S) (- (SPEC-U (AT S :END)) (SPEC-U (AT S
:BEGIN))))
on
   (SPEC-U (AT S :END)) = 1683720.0
   (SPEC-U (AT S :BEGIN)) = 1683720.0
;;; Finished <P: HB3.03A1>
```

```
;;; Answer-for :HB3.03A2: 0.0
;;; Answer is correct! Given (0 KJ/KG) =~ 0.0
;;; (NVALUE (DELTA-SPEC-H S) 0.0)
Found (SPEC-H (AT S :BEGIN)) = 2237880.0
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :BEGIN)) (* (CP WATER) (T (AT S :BEGIN))))
on
   (T (AT S :BEGIN)) = 1200
   (CP WATER) = 1864.9
Found (T (AT S :END)) = 1200
using equality
    (:= (T (AT S :BEGIN)) (T (AT S :END)))
Found (SPEC-H (AT S :END)) = 2237880.0
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :END)) (* (CP WATER) (T (AT S :END))))
on
   (T (AT S :END)) = 1200
   (CP WATER) = 1864.9
Found (DELTA-SPEC-H S) = 0.0
using
    DELTA-SPEC-H
    (:= (DELTA-SPEC-H S) (- (SPEC-H (AT S :END)) (SPEC-H (AT S
:BEGIN))))
on
   (SPEC-H (AT S :END)) = 2237880.0
   (SPEC-H (AT S :BEGIN)) = 2237880.0
;;; Finished <P: HB3.03A2>

;;; Answer-for :HB3.03C1: 22344.0
;;; Answer is correct! Given (22.3 KJ/KG) =~ 22.344
;;; (NVALUE (DELTA-SPEC-U S) 22344.0)
Found (SPEC-U (AT S :BEGIN)) = 186200.0
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :BEGIN)) (* (CV NITROGEN) (T (AT S :BEGIN))))
on
   (T (AT S :BEGIN)) = 250
   (CV NITROGEN) = 744.8
Found (SPEC-U (AT S :END)) = 208544.0
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :END)) (* (CV NITROGEN) (T (AT S :END))))
on
   (T (AT S :END)) = 280
   (CV NITROGEN) = 744.8
Found (DELTA-SPEC-U S) = 22344.0
using
    DELTA-SPEC-U
    (:= (DELTA-SPEC-U S) (- (SPEC-U (AT S :END)) (SPEC-U (AT S
:BEGIN))))
on
   (SPEC-U (AT S :END)) = 208544.0
```

```
   (SPEC-U (AT S :BEGIN)) = 186200.0
;;; Finished <P: HB3.03C1>

;;; Answer-for :HB3.03C2: 31248.0
;;; Answer is correct! Given (31.23 KJ/KG) =~ 31.248
;;; (NVALUE (DELTA-SPEC-H S) 31248.0)
Found (SPEC-H (AT S :BEGIN)) = 260400.0
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :BEGIN)) (* (CP NITROGEN) (T (AT S :BEGIN))))
on
   (T (AT S :BEGIN)) = 250
   (CP NITROGEN) = 1041.6
Found (SPEC-H (AT S :END)) = 291648.0
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :END)) (* (CP NITROGEN) (T (AT S :END))))
on
   (T (AT S :END)) = 280
   (CP NITROGEN) = 1041.6
Found (DELTA-SPEC-H S) = 31248.0
using
    DELTA-SPEC-H
    (:= (DELTA-SPEC-H S) (- (SPEC-H (AT S :END)) (SPEC-H (AT S
:BEGIN))))
on
   (SPEC-H (AT S :END)) = 291648.0
   (SPEC-H (AT S :BEGIN)) = 260400.0
;;; Finished <P: HB3.03C2>
```

3.9S Indicate whether the following states for water are in the liquid, saturation, or superheated region. Specify the quality of the states in the saturation region.

State	*P*, kPa	*T*, °C	*v*, m^3/kg
1	1700	200	—
2	1200	—	0.0010
3	—	75	3.0
4	500	202	—
5	350	—	0.005

```
(add-problem-description :hb3.09
  :givens '((basic-thermodynamic-stuff (at S :begin))
            (substance-of (at S :begin) water)))

(add-problem-goal :hb3.09a
  :description :hb3.09
  :extras '((nvalue (P (at S :begin)) 1700 kPa)
            (nvalue (T (at S :begin)) 200 C))
  :goal '(find (phase-of (at s :begin)))
  :answer '(liquid (at s :begin)))

(add-problem-goal :hb3.09b
```

```
  :description :hb3.09
  :extras '((nvalue (P (at S :begin)) 1200 kPa)
            (nvalue (spec-v (at S :begin)) 0.0010 m^3/kg))
  :goal '(find (phase-of (at S :begin)))
  :answer '(liquid (at s :begin)))

(add-problem-goal :hb3.09c
  :description :hb3.09
  :extras '((nvalue (T (at S :begin)) 75 C)
            (nvalue (spec-v (at S :begin)) 3.0 m^3/kg))
  :goal '(find (nvalue (dryness (at S :begin))))
  :answer '(0.726))

(add-problem-goal :hb3.09d
  :description :hb3.09
  :extras '((nvalue (P (at S :begin)) 500 kPa)
            (nvalue (T (at S :begin)) 202 C))
  :goal '(find (phase-of (at s :begin)))
  :answer '(gas (at S :begin)))


(add-problem-goal :hb3.09e
  :description :hb3.09
  :extras '((nvalue (P (at S :begin)) 350 kPa)
            (nvalue (spec-v (at S :begin)) 0.005 m^3/kg))
  :goal '(find (nvalue (dryness (at S :begin))))
  :answer '(0.0075))


;;; Answer-for :HB3.09C: 0.724404985832397
;;; Answer is correct! Given (0.726) =~ 0.724404985832397
;;; (NVALUE (DRYNESS (AT S :BEGIN)) 0.724404985832397)
Found (SPEC-VG (AT S :BEGIN)) = 4.14093959710419
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 348.15
Found (SPEC-VF (AT S :BEGIN)) = 0.00102581618822789
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 348.15
Found (DRYNESS (AT S :BEGIN)) = 0.724404985832397
using
    V-SATURATED-STUFF
    (:= (SPEC-V (AT S :BEGIN)) (+ (SPEC-VF (AT S :BEGIN)) (* (DRYNESS
(AT S :BEGIN)) (- (SPEC-VG (AT S :BEGIN)) (SPEC-VF (AT S :BEGIN))))))
on
   (SPEC-V (AT S :BEGIN)) = 3.0
   (SPEC-VF (AT S :BEGIN)) = 0.00102581618822789
   (SPEC-VG (AT S :BEGIN)) = 4.14093959710419
;;; Finished <P: HB3.09C>


;;; Answer-for :HB3.09E: 0.00749481887640501
```

```
;;; Answer is correct! Given (0.0075) =~ 0.00749481887640501
;;; (NVALUE (DRYNESS (AT S :BEGIN)) 0.00749481887640501)
Found (SPEC-VG (AT S :BEGIN)) = 0.5243
using
    SATURATED-TABLE-P
on
   (P (AT S :BEGIN)) = 350000
Found (SPEC-VF (AT S :BEGIN)) = 0.00107855
using
    SATURATED-TABLE-P
on
   (P (AT S :BEGIN)) = 350000
Found (DRYNESS (AT S :BEGIN)) = 0.00749481887640501
using
    V-SATURATED-STUFF
    (:= (SPEC-V (AT S :BEGIN)) (+ (SPEC-VF (AT S :BEGIN)) (* (DRYNESS
(AT S :BEGIN)) (- (SPEC-VG (AT S :BEGIN)) (SPEC-VF (AT S :BEGIN))))))
on
   (SPEC-V (AT S :BEGIN)) = 0.005
   (SPEC-VF (AT S :BEGIN)) = 0.00107855
   (SPEC-VG (AT S :BEGIN)) = 0.5243
;;; Finished <P: HB3.09E>
```

3.11S Helium occupies a rigid container at the given conditions. Determine the specific volume in cubic meters per kilogram and the mass in kilograms.

$T = 20^{\circ}\text{C}$ $P = 0.1$ MPa $V = 60$ m^3

```
(add-problem-description :hb3.11
  :givens '((static-thermodynamic-stuff (at S :begin))
            (substance-of (at S :begin) helium)
            (nvalue (P (at S :begin)) 0.1 MPa)
            (nvalue (T (at S :begin)) 20 C)
            (nvalue (V (at S :begin)) 60 m^3)))

(add-problem-goal :hb3.11a
  :description :hb3.11
  :goal '(find (nvalue (spec-v (at S :begin))))
  :answer '(6.088813445 m^3/kg))

(add-problem-goal :hb3.11b
  :description :hb3.11
  :goal '(find (nvalue (mass (at S :begin))))
  :answer '(9.859 kg))
```

```
;;; Answer-for :HB3.11A: 6.088813445
;;; Answer is correct! Given (6.088813445 M^3/KG) =~ 6.088813445
;;; (NVALUE (SPEC-V (AT S :BEGIN)) 6.088813445)
Found (SPEC-V (AT S :BEGIN)) = 6.088813445
using
    IDEAL-GAS-SPEC-VOLUME
```

```
    (:= (* (P (AT S :BEGIN)) (SPEC-V (AT S :BEGIN))) (* (R HELIUM) (T
(AT S :BEGIN))))
on
   (P (AT S :BEGIN)) = 100000.0
   (T (AT S :BEGIN)) = 293.15
   (R HELIUM) = 2077.03
;;; Finished <P: HB3.11A>


;;; Answer-for :HB3.11B: 9.85413669542966
;;; Answer is correct! Given (9.859 KG) =~ 9.85413669542966
;;; (NVALUE (MASS (AT S :BEGIN)) 9.85413669542966)
Found (MASS (AT S :BEGIN)) = 9.85413669542966
using
    IDEAL-GAS-LAW
    (:= (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (* (MASS (AT S
:BEGIN)) (R HELIUM) (T (AT S :BEGIN))))
on
   (P (AT S :BEGIN)) = 100000.0
   (T (AT S :BEGIN)) = 293.15
   (V (AT S :BEGIN)) = 60
   (R HELIUM) = 2077.03
;;; Finished <P: HB3.11B>
```

3.13E Given an ideal gas with the following data, determine the molecular weight of the gas.

$P = 300\text{psi}$ $T = 100^{\circ}\text{F}$ $V = 1.16\ \text{ft}^3/\text{lbm}$

```
(add-problem :hb3.13
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (ideal-gas (at S :begin))
           (substance-of (at s :begin) mystery)
           (nvalue (P (at S :begin)) 300 psi)
           (nvalue (T (at S :begin)) 100 F)
           (nvalue (spec-v (at S :begin)) 1.16 ft^3/lbm)
           )
 :goal '(find (nvalue (molar-mass mystery)))
 :answer '(17.3 lbm/lbmole))


;;; Answer-for :HB3.13: 0.0172582511234652
;;; Answer is correct! Given (17.3 LBM/LBMOLE) =~ 17.2582511234652
;;; (NVALUE (MOLAR-MASS MYSTERY) 0.0172582511234652)
Found (R MYSTERY) = 481.740585446452
using
    IDEAL-GAS-SPEC-VOLUME
    (:= (* (P (AT S :BEGIN)) (SPEC-V (AT S :BEGIN))) (* (R MYSTERY)
(T (AT S :BEGIN))))
on
   (P (AT S :BEGIN)) = 2068440
   (T (AT S :BEGIN)) = 310.927777777778
   (SPEC-V (AT S :BEGIN)) = 0.0724152161523809
```

```
Found (MOLAR-MASS MYSTERY) = 0.0172582511234652
using
    R-TO-R0-DEF
    (:= (R MYSTERY) (/ (R :UNIVERSAL) (MOLAR-MASS MYSTERY)))
on
   (R :UNIVERSAL) = 8.314
   (R MYSTERY) = 481.740585446452
;;; Finished <P: HB3.13>
```

3.15S The Liter-than-Air Balloon Company has a helium balloon that will be used in an attempted crossing of the Atlantic Ocean. The helium will initially be at 20°C and 500 kPa. The balloon, a rigid sphere, has a radius of 25 m. Determine the mass of the helium in kilograms.

```
(add-problem :hb3.15
  :givens '((static-thermodynamic-stuff (at S :begin))
            (balloon (at can :begin))
            (inside (at S :begin) (at can :begin))
            (substance-of (at S :begin) helium)
            (nvalue (P (at S :begin)) 500 kPa)
            (nvalue (T (at S :begin)) 20 C)
            (nvalue (radius (at can :begin)) 25 m))
  :goal '(find (nvalue (mass (at S :begin))))
  :answer '(53770 kg))
```

```
;;; Answer-for :HB3.15: 53745.9782115129
;;; Answer is correct! Given (53770 KG) =~ 53745.9782115129
;;; (NVALUE (MASS (AT S :BEGIN)) 53745.9782115129)
Found (V (AT CAN :BEGIN)) = 65449.8469497874
using equality
    (:= (V (AT CAN :BEGIN)) (* PI (/ 4 3) (RADIUS (AT CAN :BEGIN))
(RADIUS (AT CAN :BEGIN)) (RADIUS (AT CAN :BEGIN))))
Found (V (AT S :BEGIN)) = 65449.8469497874
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT S :BEGIN)))
Found (MASS (AT S :BEGIN)) = 53745.9782115129
using
    IDEAL-GAS-LAW
    (:= (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (* (MASS (AT S
:BEGIN)) (R HELIUM) (T (AT S :BEGIN))))
on
   (P (AT S :BEGIN)) = 500000
   (T (AT S :BEGIN)) = 293.15
   (R HELIUM) = 2077.03
   (V (AT S :BEGIN)) = 65449.8469497874
;;; Finished <P: HB3.15>
```

3.17S If a newer model of the balloon in Prob. 3.15S were to have its allowable mass

cut by 26,690 kg, what gas could be used in place of helium?

```
(add-problem :hb3.17
  :givens '((static-thermodynamic-stuff (at S :begin))
            (balloon (at can :begin))
            (inside (at S :begin) (at can :begin))
            (substance-of (at S :begin) mystery)
            (nvalue (P (at S :begin)) 500 kPa)
            (nvalue (T (at S :begin)) 20 C)
            (nvalue (mass (at S :begin)) 27084)
            (nvalue (radius (at can :begin)) 25 m)
            (ideal-gas-substance mystery))
  :goal '(find (nvalue (R mystery)))
  :answer '(4.124 kj/kgK))


;;; Answer-for :HB3.17: 4121.69580285994
;;; Answer is correct! Given (4.124 KJ/KGK) =~ 4.12169580285994
;;; (NVALUE (R MYSTERY) 4121.69580285994)
Found (V (AT CAN :BEGIN)) = 65449.8469497874
using equality
    (:= (V (AT CAN :BEGIN)) (* PI (/ 4 3) (RADIUS (AT CAN :BEGIN))
(RADIUS (AT CAN :BEGIN)) (RADIUS (AT CAN :BEGIN))))
Found (V (AT S :BEGIN)) = 65449.8469497874
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT S :BEGIN)))
Found (R MYSTERY) = 4121.69580285994
using
    IDEAL-GAS-LAW
    (:= (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (* (MASS (AT S
:BEGIN)) (R MYSTERY) (T (AT S :BEGIN))))
on
   (P (AT S :BEGIN)) = 500000
   (T (AT S :BEGIN)) = 293.15
   (MASS (AT S :BEGIN)) = 27084
   (V (AT S :BEGIN)) = 65449.8469497874
;;; Finished <P: HB3.17>
```

NOTE: For Probs. 3.18 through 3.35, assume the substance is water and find the required properties, using the necessary tables. Compare the results with values from the computerized tables.

3.19S Given water at $T = 200^{\circ}$C and $h = 852.38$ kJ/kg. Find P and v.

```
(add-problem :hb3.19a
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) water)
           (nvalue (spec-h (at S :begin)) 852385 J/kg)
           (nvalue (T (at S :begin)) 200 C))
 :goal '(find (nvalue (P (at S :begin))))
  :answer '(1.5536 MPa))
```

```
(add-problem :hb3.19b
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) water)
           (nvalue (spec-h (at S :begin)) 852385 J/kg)
           (nvalue (T (at S :begin)) 200 C))
 :goal '(find (nvalue (spec-v (at S :begin))))
  :answer '(0.001156 m^3/kg))

;;; Answer-for :HB3.19A: 1553679.36925098
;;; Answer is correct! Given (1.5536 MPA) =~ 1.55367936925098
;;; (NVALUE (P (AT S :BEGIN)) 1553679.36925098)
Found (P (AT S :BEGIN)) = 1553679.36925098
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 473.15
;;; Finished <P: HB3.19A>


;;; Answer-for :HB3.19B: 0.00115642752816558
;;; Answer is correct! Given (0.001156 M^3/KG) =~ 0.00115642752816558
;;; (NVALUE (SPEC-V (AT S :BEGIN)) 0.00115642752816558)
Found (SPEC-VG (AT S :BEGIN)) = 0.127320367936925
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 473.15
Found (SPEC-HG (AT S :BEGIN)) = 2792558.86990802
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 473.15
Found (SPEC-HF (AT S :BEGIN)) = 852384.809461235
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 473.15
Found (DRYNESS (AT S :BEGIN)) = 9.82070468911354E-8
using
    H-SATURATED-STUFF
    (:= (SPEC-H (AT S :BEGIN)) (+ (SPEC-HF (AT S :BEGIN)) (* (DRYNESS
(AT S :BEGIN)) (- (SPEC-HG (AT S :BEGIN)) (SPEC-HF (AT S :BEGIN))))))
on
   (SPEC-H (AT S :BEGIN)) = 852385
   (SPEC-HF (AT S :BEGIN)) = 852384.809461235
   (SPEC-HG (AT S :BEGIN)) = 2792558.86990802
Found (SPEC-VF (AT S :BEGIN)) = 0.00115641513797635
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 473.15
Found (SPEC-V (AT S :BEGIN)) = 0.00115642752816558
using
    V-SATURATED-STUFF
    (:= (SPEC-V (AT S :BEGIN)) (+ (SPEC-VF (AT S :BEGIN)) (* (DRYNESS
(AT S :BEGIN)) (- (SPEC-VG (AT S :BEGIN)) (SPEC-VF (AT S :BEGIN))))))
```

```
on
   (SPEC-VF (AT S :BEGIN)) = 0.00115641513797635
   (DRYNESS (AT S :BEGIN)) = 9.82070468911354E-8
   (SPEC-VG (AT S :BEGIN)) = 0.127320367936925
```
;;; Finished <P: HB3.19B>

3.21S Given water at P = 0.3 MPa and h = 334.90 kJ/kg. Find v.

```
(add-problem :hb3.21
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) water)
           (nvalue (P (at S :begin)) 0.3 MPa)
           (nvalue (spec-h (at S :begin)) 334.90 kJ/kg))
 :goal '(find (nvalue (spec-v (at S :begin))))
  :answer '(0.0010291 m^3/kg))


;;; Answer-for :HB3.21: 0.00102886972089695
;;; Answer is correct! Given (0.0010291 M^3/KG) =~
0.00102886972089695
;;; (NVALUE (SPEC-V (AT S :BEGIN)) 0.00102886972089695)
Found (SPEC-V (AT S :BEGIN)) = 0.00102886972089695
using
    SUBCOOLED-P-SPEC-H
on
   (P (AT S :BEGIN)) = 300000.0
   (SPEC-H (AT S :BEGIN)) = 334900.0
;;; Finished <P: HB3.21>
```

3.23S Given water at T = 170°C and x = .045. Find P and v.

```
(add-problem :hb3.23a
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) water)
           (nvalue (T (at S :begin)) 170 C)
           (nvalue (dryness (at S :begin)) 0.45))
 :goal '(find (nvalue (P (at S :begin))))
  :answer '(791.47 kPa))

(add-problem :hb3.23b
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) water)
           (nvalue (T (at S :begin)) 170 C)
           (nvalue (dryness (at S :begin)) 0.45))
 :goal '(find (nvalue (spec-v (at S :begin))))
  :answer '(0.1099 m^3/kg))

;;; Answer-for :HB3.23A: 791518.624641833
;;; Answer is correct! Given (791.47 KPA) =~ 791.518624641833
;;; (NVALUE (P (AT S :BEGIN)) 791518.624641833)
Found (P (AT S :BEGIN)) = 791518.624641833
using
    SATURATED-TABLE-T
```

```
on
   (T (AT S :BEGIN)) = 443.15
;;; Finished <P: HB3.23A>

;;; Answer-for :HB3.23B: 0.109899627277937
;;; Answer is correct! Given (0.1099 M^3/KG) =~ 0.109899627277937
;;; (NVALUE (SPEC-V (AT S :BEGIN)) 0.109899627277937)
Found (SPEC-VG (AT S :BEGIN)) = 0.242859598853868
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 443.15
Found (SPEC-VF (AT S :BEGIN)) = 0.00111419598853868
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 443.15
Found (SPEC-V (AT S :BEGIN)) = 0.109899627277937
using
    V-SATURATED-STUFF
    (:= (SPEC-V (AT S :BEGIN)) (+ (SPEC-VF (AT S :BEGIN)) (* (DRYNESS
(AT S :BEGIN)) (- (SPEC-VG (AT S :BEGIN)) (SPEC-VF (AT S :BEGIN))))))
on
   (DRYNESS (AT S :BEGIN)) = 0.45
   (SPEC-VF (AT S :BEGIN)) = 0.00111419598853868
   (SPEC-VG (AT S :BEGIN)) = 0.242859598853868
;;; Finished <P: HB3.23B>
```

3.25E Given water at $T = 400^{\circ}$F and $P = 1500$ psia. Find *u*.

```
(add-problem :hb3.25
  :givens '((basic-thermodynamic-stuff (at S :begin))
            (substance-of (at S :begin) water)
            (nvalue (T (at S :begin)) 400 F)
            (nvalue (P (at S :begin)) 1500 psi))
  :goal '(find (nvalue (spec-u (at S :begin))))
  :answer '(371.44 btu/lbm))

;;; Answer-for :HB3.25: 863927.232777778
;;; Answer is correct! Given (371.44 BTU/LBM) =~ 371.447765675829
;;; (NVALUE (SPEC-U (AT S :BEGIN)) 863927.232777778)
Found (SPEC-U (AT S :BEGIN)) = 863927.232777778
using
    SUBCOOLED-P-T
on
   (T (AT S :BEGIN)) = 477.594444444444
   (P (AT S :BEGIN)) = 10342200
```

;;; Finished <P: HB3.25>

3.27S Given water at $T = 120^{\circ}$C and $P = 0.5$ MPa. Find *h*.

```
(add-problem :hb3.27
 :givens '((basic-thermodynamic-stuff (at S :begin))
```

```
           (substance-of (at S :begin) water)
           (nvalue (T (at S :begin)) 120 C)
           (nvalue (P (at S :begin)) 0.5 MPa))
 :goal '(find (nvalue (spec-h (at S :begin))))
  :answer '(503.78 kJ/kg))

;;; Answer-for :HB3.27: 503990.0
;;; Answer is correct! Given (503.78 KJ/KG) =~ 503.99
;;; (NVALUE (SPEC-H (AT S :BEGIN)) 503990.0)
Found (SPEC-H (AT S :BEGIN)) = 503990.0
using
    SUBCOOLED-P-T
on
   (T (AT S :BEGIN)) = 393.15
   (P (AT S :BEGIN)) = 500000.0
;;; Finished <P: HB3.27>
```

3.29S Given water at $T = 200^{\circ}$C and $h = 1800$ kJ/kg. Find P and v.

```
(add-problem :hb3.29a
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) water)
           (nvalue (T (at S :begin)) 500 F)
           (nvalue (spec-h (at S :begin)) 800 btu/lbm))
 :goal '(find (nvalue (P (at S :begin))))
  :answer '(680.11 psi))

(add-problem :hb3.29b
  :givens '((basic-thermodynamic-stuff (at S :begin))
            (substance-of (at S :begin) water)
            (nvalue (T (at S :begin)) 500 F)
            (nvalue (spec-h (at S :begin)) 800 btu/lbm))
  :goal '(find (nvalue (spec-v (at S :begin))))
  :answer '(0.3070 ft^3/lbm))

;;; Answer-for :HB3.29A: 4689553.3686601
;;; Answer is correct! Given (680.11 PSI) =~ 680.157998587356
;;; (NVALUE (P (AT S :BEGIN)) 4689553.3686601)
Found (P (AT S :BEGIN)) = 4689553.3686601
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 533.15
;;; Finished <P: HB3.29A>


;;; Answer-for :HB3.29B: 0.0191634147868048
;;; Answer is correct! Given (0.307 FT^3/LBM) =~ 0.306973621481936
;;; (NVALUE (SPEC-V (AT S :BEGIN)) 0.0191634147868048)
Found (SPEC-VG (AT S :BEGIN)) = 0.042204466313399
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 533.15
Found (SPEC-HG (AT S :BEGIN)) = 2796183.57305072
```

```
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 533.15
Found (SPEC-HF (AT S :BEGIN)) = 1134396.79031037
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 533.15
Found (DRYNESS (AT S :BEGIN)) = 0.437043675660667
using
    H-SATURATED-STUFF
    (:= (SPEC-H (AT S :BEGIN)) (+ (SPEC-HF (AT S :BEGIN)) (* (DRYNESS
(AT S :BEGIN)) (- (SPEC-HG (AT S :BEGIN)) (SPEC-HF (AT S :BEGIN))))))
on
   (SPEC-H (AT S :BEGIN)) = 1055000000/567
   (SPEC-HF (AT S :BEGIN)) = 1134396.79031037
   (SPEC-HG (AT S :BEGIN)) = 2796183.57305072
Found (SPEC-VF (AT S :BEGIN)) = 0.00127580003785011
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 533.15
Found (SPEC-V (AT S :BEGIN)) = 0.0191634147868048
using
    V-SATURATED-STUFF
    (:= (SPEC-V (AT S :BEGIN)) (+ (SPEC-VF (AT S :BEGIN)) (* (DRYNESS
(AT S :BEGIN)) (- (SPEC-VG (AT S :BEGIN)) (SPEC-VF (AT S :BEGIN))))))
on
   (SPEC-VF (AT S :BEGIN)) = 0.00127580003785011
   (DRYNESS (AT S :BEGIN)) = 0.437043675660667
   (SPEC-VG (AT S :BEGIN)) = 0.042204466313399
;;; Finished <P: HB3.29B>
```

3.31S Given water at $T = 210^{\circ}$C and $P = 3.0$ MPa. Find u and h.

```
(add-problem :hb3.31a
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) water)
           (nvalue (T (at S :begin)) 210 C)
           (nvalue (P (at S :begin)) 3 MPa))
 :goal '(find (nvalue (spec-u (at S :begin))))
  :answer '(895.43 kJ/kg))

(add-problem :hb3.31b
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) water)
           (nvalue (T (at S :begin)) 210 C)
           (nvalue (P (at S :begin)) 3 MPa))
  :goal '(find (nvalue (spec-h (at S :begin))))
  :answer '(898.94 kJ/kg))

;;; Answer-for :HB3.31A: 894530.740740741
;;; Answer is correct! Given (895.43 KJ/KG) =~ 894.530740740741
;;; (NVALUE (SPEC-U (AT S :BEGIN)) 894530.740740741)
```

```
Found (SPEC-U (AT S :BEGIN)) = 894530.740740741
using
    SUBCOOLED-P-T
on
   (T (AT S :BEGIN)) = 483.15
   (P (AT S :BEGIN)) = 3000000
;;; Finished <P: HB3.31A>


;;; Answer-for :HB3.31B: 898035.925925926
;;; Answer is correct! Given (898.94 KJ/KG) =~ 898.035925925926
;;; (NVALUE (SPEC-H (AT S :BEGIN)) 898035.925925926)
Found (SPEC-H (AT S :BEGIN)) = 898035.925925926
using
    SUBCOOLED-P-T
on
   (T (AT S :BEGIN)) = 483.15
   (P (AT S :BEGIN)) = 3000000
;;; Finished <P: HB3.31B>
```

3.33E Given water at P = 2000 psia and v = 0.01844 ft^3/lbm. Find T and h.

```
(add-problem :hb3.33a
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) water)
           (nvalue (spec-v (at S :begin)) 0.01844 ft^3/lbm)
           (nvalue (P (at S :begin)) 2000 psi))
 :goal '(find (nvalue (T (at S :begin))))
  :answer '(385.7 F))

(add-problem :hb3.33b
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) water)
           (nvalue (spec-v (at S :begin)) 0.01844 ft^3/lbm)
           (nvalue (P (at S :begin)) 2000 psi))
 :goal '(find (nvalue (spec-h (at S :begin))))
  :answer '(365.8 btu/lbm))

;;; Answer-for :HB3.33A: 478.15
;;; Answer is correct! Given (385.7 F) =~ 401.0
;;; (NVALUE (T (AT S :BEGIN)) 478.15)
Found (T (AT S :BEGIN)) = 478.15
using
    SUBCOOLED-P-SPEC-V
on
   (SPEC-V (AT S :BEGIN)) = 0.00115115222918095
   (P (AT S :BEGIN)) = 13789600
;;; Finished <P: HB3.33A>

;;; Answer-for :HB3.33B: 879781.257142857
;;; Answer is correct! Given (365.8 BTU/LBM) =~ 378.264244777251
;;; (NVALUE (SPEC-H (AT S :BEGIN)) 879781.257142857)
Found (SPEC-H (AT S :BEGIN)) = 879781.257142857
using
    SUBCOOLED-P-SPEC-V
```

```
on
   (SPEC-V (AT S :BEGIN)) = 0.00115115222918095
   (P (AT S :BEGIN)) = 13789600
;;; Finished <P: HB3.33B>
```

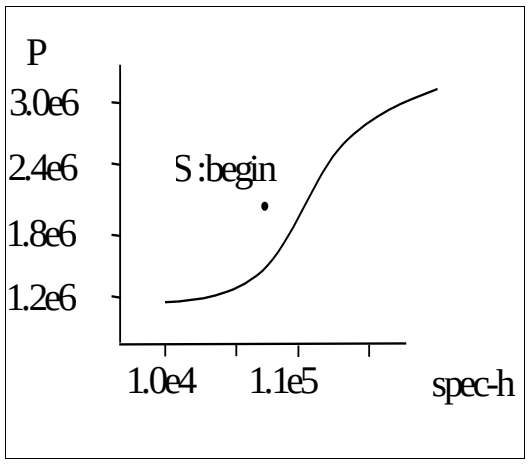
3.35S Given water at $T = 400^{\circ}$C and $v = 0.5137$ m^3/kg. Find P and h.

```
(add-problem-description :hb3.35
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) water)
           (nvalue (spec-v (at S :begin)) 0.5137)
           (nvalue (T (at S :begin)) 400 C)))

(add-problem-goal :hb3.35a
  :description :hb3.35
  :goal '(find (nvalue (P (at S :begin))))
  :answer '(600 kPa))

(add-problem-goal :hb3.35b
  :description :hb3.35
  :goal '(find (nvalue (spec-h (at S :begin))))
  :answer '(3270.2 kJ/kg))

;;; Answer-for :HB3.35A: 600027.037988374
;;; Answer is correct! Given (600 KPA) =~ 600.027037988374
;;; (NVALUE (P (AT S :BEGIN)) 600027.037988374)
Found (P (AT S :BEGIN)) = 600027.037988374
using
    SUPERHEATED-T-SPEC-V
on
   (SPEC-V (AT S :BEGIN)) = 0.5137
   (T (AT S :BEGIN)) = 673.15
;;; Finished <P: HB3.35A>


;;; Solving <P: HB3.35B>
;;; Aborted :HB3.35B with SOLVED
;;; Time spent: 3 seconds
;;; Answer-for :HB3.35B: 3270199.56739219
;;; Answer is correct! Given (3270.2 KJ/KG) =~ 3270.19956739219
;;; (NVALUE (SPEC-H (AT S :BEGIN)) 3270199.56739219)
Found (SPEC-H (AT S :BEGIN)) = 3270199.56739219
using
    SUPERHEATED-T-SPEC-V
on
   (SPEC-V (AT S :BEGIN)) = 0.5137
   (T (AT S :BEGIN)) = 673.15
;;; Finished <P: HB3.35B>
```

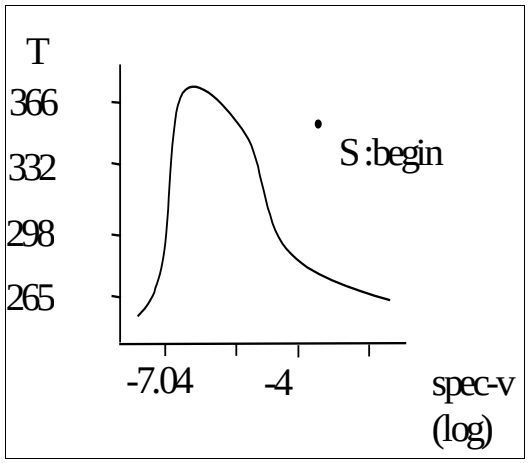
3.37S Indicate whether the following states for refrigerant 12 are in the subcooled, saturation, or superheated regions. The reference values for u and h are those used for Tables D.13 through D.15.

State	P, kPa	*T*, °C	*v*, m³/kg	*u*, kJ/kg	*h*, kJ/kg
1	2000	—	—	—	220
2	—	100	0.04	—	—
3	—	—	0.02	325	—
4	2000	—	—	—	300
5	600	200	—	—	—
6	—	—	0.30	—	365

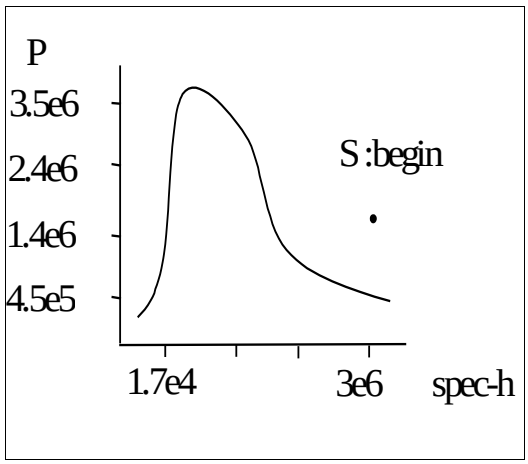
```
(add-problem :hb3.37a
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) refrigerant-12)
           (:not (ideal-gas-substance refrigerant-12))
           (nvalue (P (at S :begin)) 2000 kPa)
           (nvalue (spec-h (at S :begin)) 70 kj/kg))
 :goal '(find (phase-of (at S :begin)))
 :answer '(liquid (at s :begin)))
```



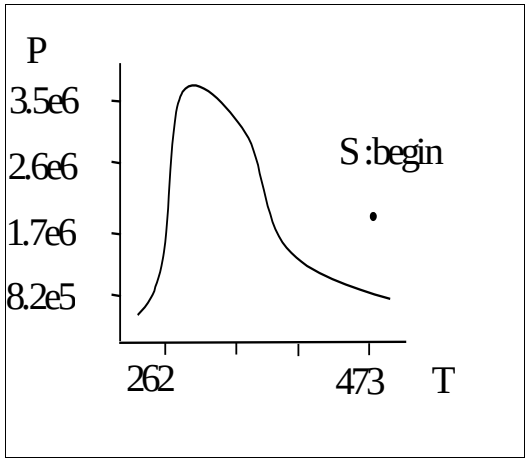

```
(add-problem :hb3.37b
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) refrigerant-12)
           (nvalue (T (at S :begin)) 100 C)
           (nvalue (spec-v (at S :begin)) 0.04))
 :goal '(find (phase-of (at S :begin)))
 :answer '(gas (at s :begin)))
```




```
(add-problem :hb3.37c
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) refrigerant-12)
           (nvalue (spec-u (at S :begin)) 325 kJ/kg)
           (nvalue (spec-h (at S :begin)) 0.02 kj/kg))
 :goal '(find (phase-of (at S :begin)))
 :answer '(gas (at s :begin)))

;; no graph is possible for spec-u versus spec-h
;; using tables

(> (spec-u (at s :begin)) (spec-ug (at s :begin)))


(add-problem :hb3.37d
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) refrigerant-12)
           (nvalue (P (at S :begin)) 2000 kPa)
           (nvalue (spec-h (at S :begin)) 300 kj/kg))
 :goal '(find (phase-of (at S :begin)))
 :answer '(gas (at s :begin)))
```



```
(add-problem :hb3.37e
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) refrigerant-12)
           (nvalue (P (at S :begin)) 600 kPa)
           (nvalue (T (at S :begin)) 200 C))
 :goal '(find (phase-of (at S :begin)))
 :answer '(gas (at s :begin)))
```




```
(add-problem :hb3.37f
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) refrigerant-12)
           (nvalue (spec-h (at S :begin)) 365 kJ/kg)
           (nvalue (spec-v (at S :begin)) 0.30 m^3/kg))
 :goal '(find (phase-of (at S :begin)))
 :answer '(gas (at s :begin)))

;; no graph is possible for spec-h versus spec-v
;; using tables

(> (spec-u (at s :begin)) (spec-ug (at s :begin)))
```

3.39S Find the change in value of enthalpy h for water (steam) between an initial state where P = 100 kPa and v = 1.6500 m^3/kg and a final state where P = 3000 kPa and T= 525°C.

```
(add-problem :hb3.39
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) water)
           (nvalue (P (at S :begin)) 100 kPa)
           (nvalue (spec-v (at S :begin)) 1.65 m^3/kg)
           (heating htr (at S :begin) (at S :end))
           (nvalue (P (at S :end)) 3000 kPa)
           (nvalue (T (at S :end)) 525 C)
           (given-equation give4
            (:= (spec-h (at S :begin :end))
```

```
             (- (spec-h (at S :end))
                (spec-h (at S :begin))))))
  :goal '(find (nvalue (spec-h (at S :begin :end))))
  :answer '(897.0 kj/kg))


;;; Answer-for :HB3.39: 896726.921218028
;;; Answer is correct! Given (897.0 KJ/KG) =~ 896.726921218028
;;; (NVALUE (SPEC-H (AT S :BEGIN :END)) 896726.921218028)
Found (SPEC-VG (AT S :BEGIN)) = 1.6943
using
    SATURATED-TABLE-P
on
   (P (AT S :BEGIN)) = 100000
Found (SPEC-VF (AT S :BEGIN)) = 0.00104313
using
    SATURATED-TABLE-P
on
   (P (AT S :BEGIN)) = 100000
Found (DRYNESS (AT S :BEGIN)) = 0.97383740129163
using
    V-SATURATED-STUFF
    (:= (SPEC-V (AT S :BEGIN)) (+ (SPEC-VF (AT S :BEGIN)) (* (DRYNESS
(AT S :BEGIN)) (- (SPEC-VG (AT S :BEGIN)) (SPEC-VF (AT S :BEGIN))))))
on
   (SPEC-V (AT S :BEGIN)) = 1.65
   (SPEC-VF (AT S :BEGIN)) = 0.00104313
   (SPEC-VG (AT S :BEGIN)) = 1.6943
Found (SPEC-HG (AT S :BEGIN)) = 2675100.0
using
    SATURATED-TABLE-DRYNESS-SPEC-V-LOOKUP
on
   (SPEC-V (AT S :BEGIN)) = 1.65
   (DRYNESS (AT S :BEGIN)) = 0.97383740129163
Found (SPEC-HF (AT S :BEGIN)) = 417510.0
using
    SATURATED-TABLE-P
on
   (P (AT S :BEGIN)) = 100000
Found (SPEC-H (AT S :BEGIN)) = 2616035.57878197
using
    H-SATURATED-STUFF
    (:= (SPEC-H (AT S :BEGIN)) (+ (SPEC-HF (AT S :BEGIN)) (* (DRYNESS
(AT S :BEGIN)) (- (SPEC-HG (AT S :BEGIN)) (SPEC-HF (AT S :BEGIN))))))
on
   (SPEC-HF (AT S :BEGIN)) = 417510.0
   (DRYNESS (AT S :BEGIN)) = 0.97383740129163
   (SPEC-HG (AT S :BEGIN)) = 2675100.0
Found (SPEC-H (AT S :END)) = 3512762.5
using
    SUPERHEATED-P-T
on
   (P (AT S :END)) = 3000000
   (T (AT S :END)) = 798.15
Found (SPEC-H (AT S :BEGIN :END)) = 896726.921218028
using
```

```
    GIVE4
    (:= (SPEC-H (AT S :BEGIN :END)) (- (SPEC-H (AT S :END)) (SPEC-H
(AT S :BEGIN))))
on
   (SPEC-H (AT S :END)) = 3512762.5
   (SPEC-H (AT S :BEGIN)) = 2616035.57878197
;;; Finished <P: HB3.39>
```

3.43E (a) From the data in the tables, find the value of the specific heat at constant pressure c_p of ammonia at 40psia and 100F.

(b) Find the value of the quality of saturated ammonia when the temperature is 40F and the enthalpy is 500 Btu/lbm

(c) Find the enthalpy of superheated ammonia at 25 psia and 105F

```
(add-problem :hb3.43a
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) ammonia)
           (nvalue (P (at S :begin)) 40 Psi)
           (nvalue (T (at S :begin)) 100 F))
 :goal '(find (nvalue (cp (at S :begin))))
 :answer '(0.554 btu/lbmf))

(add-problem :hb3.43b
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) ammonia)
           (saturated (at S :begin))
           (nvalue (spec-h (at S :begin)) 500 Btu/lbm)
           (nvalue (T (at S :begin)) 40 F))
 :goal '(find (nvalue (dryness (at S :begin))))
 :answer '(0.769))

(add-problem :hb3.43c
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) ammonia)
           (gas (at S :begin))
           (nvalue (P (at S :begin)) 25 Psi)
           (nvalue (T (at S :begin)) 105 F))
 :goal '(find (nvalue (spec-h (at S :begin))))
 :answer '(671.01 Btu/lbm))


;;; Answer-for :HB3.43B: 0.772136823967528
;;; Answer is correct! Given (0.769) =~ 0.772136823967528
;;; (NVALUE (DRYNESS (AT S :BEGIN)) 0.772136823967528)
Found (SPEC-HG (AT S :BEGIN)) = 1446787.77777778
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 277.594444444444
Found (SPEC-HF (AT S :BEGIN)) = 201001.111111111
using
    SATURATED-TABLE-T
```

```
on
   (T (AT S :BEGIN)) = 277.594444444444
Found (DRYNESS (AT S :BEGIN)) = 0.772136823967528
using
    H-SATURATED-STUFF
    (:= (SPEC-H (AT S :BEGIN)) (+ (SPEC-HF (AT S :BEGIN)) (* (DRYNESS
(AT S :BEGIN)) (- (SPEC-HG (AT S :BEGIN)) (SPEC-HF (AT S :BEGIN))))))
on
   (SPEC-H (AT S :BEGIN)) = 659375000/567
   (SPEC-HF (AT S :BEGIN)) = 201001.111111111
   (SPEC-HG (AT S :BEGIN)) = 1446787.77777778
;;; Finished <P: HB3.43B>


;;; Answer-for :HB3.43C: 1556966.43888889
;;; Answer is correct! Given (671.01 BTU/LBM) =~ 669.421778843602
;;; (NVALUE (SPEC-H (AT S :BEGIN)) 1556966.43888889)
Found (SPEC-H (AT S :BEGIN)) = 1556966.43888889
using
    SUPERHEATED-P-T
on
   (P (AT S :BEGIN)) = 172370
   (T (AT S :BEGIN)) = 313.705555555556
;;; Finished <P: HB3.43C>
```

3.45 Find the required properties in the given states:

(*a*) $v(T = 568.8\ \text{K},\ P = 12.3\ \text{atm})$ for octane

(*b*) P or x at $T = 20^{\circ}\text{C}$, $h = 250$ kJ/kg for refrigerant 12, whichever is appropriate to define the state

(*c*) $u(P = 550\ \text{kPa},\ T = 95^{\circ}C)$ for ammonia

```
(add-problem :hb3.45a
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) octane)
           (nvalue (P (at S :begin)) 12.3 atm)
           (nvalue (T (at S :begin)) 568.8 K))
 :goal '(find (nvalue (spec-v (at S :begin))))
 :answer '(0.02685))


(add-problem :hb3.45b
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) refrigerant-12)
           (:not (ideal-gas-substance refrigerant-12))
           (nvalue (spec-h (at S :begin)) 86.01 kJ/kg)
           (nvalue (T (at S :begin)) 20 C)
           (saturated (at s :begin)))
 :goal '(find (nvalue (dryness (at S :begin))))
 :answer '(0.221))

(add-problem :hb3.45c
 :givens '((basic-thermodynamic-stuff (at S :begin))
```

```
           (substance-of (at S :begin) ammonia)
           (nvalue (P (at S :begin)) 550 kPa)
           (nvalue (T (at S :begin)) 95 C))
 :goal '(find (nvalue (spec-u (at S :begin))))
 :answer '(1511.3 kJ/kg))


;;; Answer-for :HB3.45B: 0.220992122631467
;;; Answer is correct! Given (0.221) =~ 0.220992122631467
;;; (NVALUE (DRYNESS (AT S :BEGIN)) 0.220992122631467)
Found (SPEC-HG (AT S :BEGIN)) = 195780.0
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 293.15
Found (SPEC-HF (AT S :BEGIN)) = 54870.0
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 293.15
Found (DRYNESS (AT S :BEGIN)) = 0.220992122631467
using
    H-SATURATED-STUFF
    (:= (SPEC-H (AT S :BEGIN)) (+ (SPEC-HF (AT S :BEGIN)) (* (DRYNESS
(AT S :BEGIN)) (- (SPEC-HG (AT S :BEGIN)) (SPEC-HF (AT S :BEGIN))))))
on
   (SPEC-H (AT S :BEGIN)) = 86010.0
   (SPEC-HF (AT S :BEGIN)) = 54870.0
   (SPEC-HG (AT S :BEGIN)) = 195780.0
```

;;; Finished <P: HB3.45B>

```
;;; Answer-for :HB3.45C: 1491475.0
;;; Answer is correct! Given (1511.3 KJ/KG) =~ 1491.475
;;; (NVALUE (SPEC-U (AT S :BEGIN)) 1491475.0)
Found (SPEC-U (AT S :BEGIN)) = 1491475.0
using
    SUPERHEATED-P-T
on
   (P (AT S :BEGIN)) = 550000
   (T (AT S :BEGIN)) = 368.15
;;; Finished <P: HB3.45C>
```

3.49S Find the values of u and h for water at T = 100°C and P = 300 kPa.

```
(add-problem-description :hb3.49
 :givens '((basic-thermodynamic-stuff (at S :begin))
           (substance-of (at S :begin) water)
           (nvalue (T (at S :begin)) 100 C)
           (nvalue (P (at S :begin)) 300 kPa)))

(add-problem-goal :hb3.49a
  :description :hb3.49
  :goal '(find (nvalue (spec-u (at S :begin))))
  :answer '(418.96 kJ/kg))
```

```
(add-problem-goal :hb3.49b
  :description :hb3.49
  :goal '(find (nvalue (spec-h (at S :begin))))
  :answer '(419.3 kJ/kg))

;;; Answer-for :HB3.49A: 418088.61948261
;;; Answer is correct! Given (418.96 KJ/KG) =~ 418.08861948261
;;; (NVALUE (SPEC-U (AT S :BEGIN)) 418088.61948261)
Found (SPEC-U (AT S :BEGIN)) = 418088.61948261
using
    SUBCOOLED-P-T
on
   (T (AT S :BEGIN)) = 373.15
   (P (AT S :BEGIN)) = 300000
```

;;; Finished <P: HB3.49A>

```
;;; Answer-for :HB3.49B: 420574.984650519
;;; Answer is correct! Given (419.3 KJ/KG) =~ 420.574984650519
;;; (NVALUE (SPEC-H (AT S :BEGIN)) 420574.984650519)
Found (SPEC-H (AT S :BEGIN)) = 420574.984650519
using
    SUBCOOLED-P-T
on
   (T (AT S :BEGIN)) = 373.15
   (P (AT S :BEGIN)) = 300000
;;; Finished <P: HB3.49B>
```

3.57S A piston encloses 1 kg of saturated water which is initially 10.0 percent liquid on a mass basis. The initial pressure is 1.0 MPa. The water is heated in the system shown in Fig. P3.57 until the water is at the saturated vapor state. The volume at the top stops is 0.19 m^3. Determine the work done by the water and the final temperature and pressure.

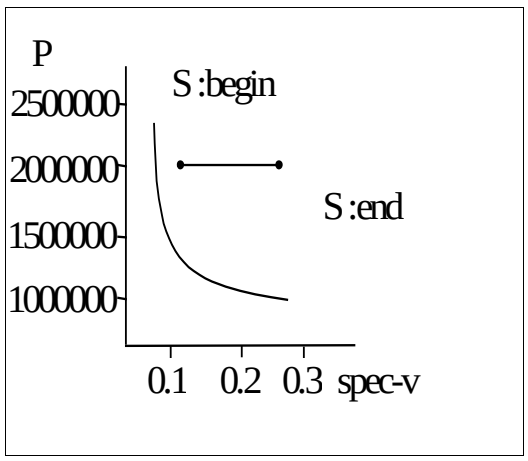
```
(add-problem :hb3.57
  :givens '((piston (at can :begin))
            (static-thermodynamic-stuff (at S :begin))
            (inside (at S :begin) (at can :begin))
            (direction (at can :begin) :up)
            (piston-stop-for (at can :begin) (at Stop :begin))
            (over (at Stop :begin) (top (at can :begin)))
            (substance-of (at S :begin) water)
            (saturated (at S :begin))
            (heating htr (at s :begin) (at s :end))
            (saturated (at s :begin))
            (nvalue (dryness (at s :begin)) 0.9)
            (nvalue (mass (at S :begin)) 1 kg)
            (nvalue (P (at S :begin)) 1 MPa)
            (saturated-vapor (at S :end))
            (nvalue (V (at can :end)) 0.19 m^3))
  :goal '(find (nvalue (work htr)))
  :answer '(15 kJ))

(add-problem-goal :hb3.57b
```

```
  :description :hb3.57
  :goal '(find (nvalue (T (at s :end))))
  :answer '(181 C))

(add-problem-goal :hb3.57c
  :description :hb3.57
  :goal '(find (nvalue (P (at s :end))))
  :answer '(1025 MPa))


;;; Answer-for :HB3.57B: 454.12002247191
;;; Answer is correct! Given (181 C) =~ 180.97002247191
;;; (NVALUE (T (AT S :END)) 454.12002247191)
Found (MASS-BEGIN HTR) = 1
using equality
    (:= (MASS-BEGIN HTR) (MASS (AT S :BEGIN)))
Found (MASS-END HTR) = 1
using
    CONSERVATION-OF-MASS
    (:= (+ (MASS-BEGIN HTR) (MASS-INLET HTR)) (+ (MASS-END HTR)
(MASS-OUTLET HTR)))
on
   (MASS-BEGIN HTR) = 1
   (MASS-OUTLET HTR) = 0
   (MASS-INLET HTR) = 0
Found (MASS (AT S :END)) = 1
using equality
    (:= (MASS-END HTR) (MASS (AT S :END)))
Found (V (AT S :END)) = 0.19
using equality
    (:= (V (AT CAN :END)) (V (AT S :END)))
Found (SPEC-V (AT S :END)) = 0.19
using
    SPEC-V-DEFINITION
    (:= (SPEC-V (AT S :END)) (/ (V (AT S :END)) (MASS (AT S :END))))
on
   (V (AT S :END)) = 0.19
   (MASS (AT S :END)) = 1
Found (T (AT S :END)) = 454.12002247191
using
    SATURATED-TABLE-DRYNESS-SPEC-V-LOOKUP
on
   (DRYNESS (AT S :END)) = 1
   (SPEC-V (AT S :END)) = 0.19
;;; Finished <P: HB3.57B>
```

4.3S A piston-cylinder arrangement initially contains water at P = 2 MPa and T = 300°C. The piston is moved to a final position where the volume is twice the initial volume. During the piston movement, there is heat transfer to the water in such a way that the pressure in the cylinder remains constant.

(*a*) Sketch the process on a *P-v* diagram, indicating the relative position of the saturation curve.
(*b*) Find the work done per kilogram of water during the expansion.
(*c*) Find the heat tranfer per kilogram of water during the expansion.
(d) Find the value of the enthalpy of the water after expansion.

```
(add-problem-goal :hb4.03a
  :description :hb4.03
  :goal '(plot-graph (P spec-v) expn))

(add-problem-goal :hb4.03b
 :description :hb4.03
 :goal '(find (nvalue (spec-work expn)))
 :answer '(250.8 kj/kg))

(add-problem-goal :hb4.03c
  :description :hb4.03
  :goal '(find (nvalue (spec-q expn)))
  :answer '(1169.9 kj/kg))


(add-problem-goal :hb4.03d
  :description :hb4.03
  :goal '(find (nvalue (spec-h (at S :end))))
  :answer '(4192.6 kj/kg))
```




```
;;; Answer-for :HB4.03B: 250900.0
;;; Answer is correct! Given (250.8 KJ/KG) =~ 250.9
;;; (NVALUE (SPEC-WORK EXPN) 250900.0)
Found (SPEC-V (AT S :BEGIN)) = 0.12545
using
    SUPERHEATED-P-T
on
   (P (AT S :BEGIN)) = 2000000
   (T (AT S :BEGIN)) = 573.15
Found (SPEC-V (AT S :END)) = 0.2509
```

```
using equality
    (:= (SPEC-V (AT S :END)) (* 2 (SPEC-V (AT S :BEGIN))))
Found (SPEC-WORK EXPN) = 250900.0
using
    SPEC-WORK=PDV-ISOBARIC
    (:= (SPEC-WORK EXPN) (* (P (AT S :BEGIN)) (- (SPEC-V (AT S :END))
(SPEC-V (AT S :BEGIN)))))
on
   (P (AT S :BEGIN)) = 2000000
   (SPEC-V (AT S :BEGIN)) = 0.12545
   (SPEC-V (AT S :END)) = 0.2509
;;; Finished <P: HB4.03B>

;;; Answer-for :HB4.03C: 1170701.96749358
;;; Answer is correct! Given (1169.9 KJ/KG) =~ 1170.70196749358
;;; (NVALUE (SPEC-Q EXPN) 1170701.96749358)
Found (SPEC-V (AT S :BEGIN)) = 0.12545
using
    SUPERHEATED-P-T
on
   (P (AT S :BEGIN)) = 2000000
   (T (AT S :BEGIN)) = 573.15
Found (SPEC-V (AT S :END)) = 0.2509
using equality
    (:= (SPEC-V (AT S :END)) (* 2 (SPEC-V (AT S :BEGIN))))
Found (SPEC-WORK EXPN) = 250900.0
using
    SPEC-WORK=PDV-ISOBARIC
    (:= (SPEC-WORK EXPN) (* (P (AT S :BEGIN)) (- (SPEC-V (AT S :END))
(SPEC-V (AT S :BEGIN)))))
on
   (P (AT S :BEGIN)) = 2000000
   (SPEC-V (AT S :BEGIN)) = 0.12545
   (SPEC-V (AT S :END)) = 0.2509
Found (P (AT S :END)) = 2000000
using equality
    (:= (P (AT S :BEGIN)) (P (AT S :END)))
Found (SPEC-U (AT S :END)) = 3691601.96749358
using
    SUPERHEATED-P-SPEC-V
on
   (P (AT S :END)) = 2000000
   (SPEC-V (AT S :END)) = 0.2509
Found (SPEC-ENERGY (AT S :END)) = 3691601.96749358
using equality
    (:= (SPEC-ENERGY (AT S :END)) (SPEC-U (AT S :END)))
Found (SPEC-ENERGY-END EXPN) = 3691601.96749358
using equality
    (:= (SPEC-ENERGY-END EXPN) (SPEC-ENERGY (AT S :END)))
Found (SPEC-U (AT S :BEGIN)) = 2771800.0
using
    SUPERHEATED-P-T
on
   (P (AT S :BEGIN)) = 2000000
   (T (AT S :BEGIN)) = 573.15
Found (SPEC-ENERGY (AT S :BEGIN)) = 2771800.0
```

```
using equality
    (:= (SPEC-ENERGY (AT S :BEGIN)) (SPEC-U (AT S :BEGIN)))
Found (SPEC-ENERGY-BEGIN EXPN) = 2771800.0
using equality
    (:= (SPEC-ENERGY-BEGIN EXPN) (SPEC-ENERGY (AT S :BEGIN)))
Found (SPEC-Q EXPN) = 1170701.96749358
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q EXPN) (SPEC-ENERGY-BEGIN EXPN) (SPEC-ENERGY-INLET
EXPN)) (+ (SPEC-ENERGY-END EXPN) (SPEC-ENERGY-OUTLET EXPN) (SPEC-WORK
EXPN)))
on
   (SPEC-ENERGY-OUTLET EXPN) = 0
   (SPEC-ENERGY-INLET EXPN) = 0
   (SPEC-ENERGY-BEGIN EXPN) = 2771800.0
   (SPEC-ENERGY-END EXPN) = 3691601.96749358
   (SPEC-WORK EXPN) = 250900.0
```

;;; Finished <P: HB4.03C>

```
;;; Answer-for :HB4.03D: 4193349.10179641
;;; Answer is correct! Given (4192.6 KJ/KG) =~ 4193.34910179641
;;; (NVALUE (SPEC-H (AT S :END)) 4193349.10179641)
Found (SPEC-V (AT S :BEGIN)) = 0.12545
using
    SUPERHEATED-P-T
on
   (P (AT S :BEGIN)) = 2000000
   (T (AT S :BEGIN)) = 573.15
Found (SPEC-V (AT S :END)) = 0.2509
using equality
    (:= (SPEC-V (AT S :END)) (* 2 (SPEC-V (AT S :BEGIN))))
Found (P (AT S :END)) = 2000000
using equality
    (:= (P (AT S :BEGIN)) (P (AT S :END)))
Found (SPEC-H (AT S :END)) = 4193349.10179641
using
    SUPERHEATED-P-SPEC-V
on
   (P (AT S :END)) = 2000000
   (SPEC-V (AT S :END)) = 0.2509
```

;;; Finished <P: HB4.03D>

4.09 In Prob. 2.75, an elevator is allowed to fall to an equilibrium position. For that problem, determine the heat transfer from the air in the elevator shaft in order for the assumption of an isothermal process to be justified.

```
(add-problem :hb4.09
  :givens '((piston (at can :begin))
            (static-thermodynamic-stuff (at S :begin))
            (inside (at S :begin) (at can :begin))
            (direction (at can :begin) :up)
            (nvalue (mass (top (at can :begin))) 1000 kg)
            (nvalue (area (top (at can :begin))) 2.5 m^2)
            (nvalue (T (at S :begin)) 27 C)
```

```
            (nvalue (P (at S :begin)) 0.1013 Mpa)
            (compressing cmp (at s :begin) (at s :end))
            (isobaric cmp)
            (isothermal cmp)
            ;; from previous problem
            (nvalue (V (at s :begin)) 150)
            (nvalue (V (at s :end)) 144.4))
  :goal '(find (nvalue (work cmp)))
  :answer '(-588.9 kJ))


;;; Answer-for :HB4.09: -567279.999999999
;;; Answer is correct! Given (-588.9 KJ) =~ -567.279999999999
;;; (NVALUE (WORK CMP) -567279.999999999)
Found (WORK CMP) = -567279.999999999
using
    WORK=PDV-ISOBARIC
    (:= (WORK CMP) (* (P (AT S :BEGIN)) (- (V (AT S :END)) (V (AT S
:BEGIN)))))
on
   (P (AT S :BEGIN)) = 101300.0
   (V (AT S :BEGIN)) = 150
   (V (AT S :END)) = 144.4
;;; Finished <P: HB4.09>
```

4.15 A storage tank contains air at the same temperature as the surroundings (35°C). Suddenly it begins to rain, and the surrounding temperature drops to 20°C. The tank was initially at a pressure of 200 kPa, and the tank volume is 10 in^3.

```
(add-problem-description :hb4.15
 :givens '((container (at can :begin))
           (closed (at can :begin))
           (rigid (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (substance-of (at s :begin) AIR)
           (nvalue (T (at S :begin)) 35 C)
           (nvalue (P (at S :begin)) 200 kPa)
           (nvalue (V (at can :begin)) 10 m^3)
           (cooling cool (at s :begin) (at s :end))
           (nvalue (T (at S :end)) 20 C)))

(add-problem-goal :hb4.15a
  :description :hb4.15
  :goal '(find (nvalue (P (at s :end))))
  :answer '(190.3 kPa))

(add-problem-goal :hb4.15b
  :description :hb4.15
  :goal '(find (nvalue (Q cool)))
  :answer '(-243.7 kj))


;;; Answer-for :HB4.15A: 190264.481583644
;;; Answer is correct! Given (190.3 KPA) =~ 190.264481583644
```

```
;;; (NVALUE (P (AT S :END)) 190264.481583644)
Found (V (AT CAN :END)) = 10
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT CAN :END)))
Found (V (AT S :END)) = 10
using equality
    (:= (V (AT CAN :END)) (V (AT S :END)))
Found (V (AT S :BEGIN)) = 10
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT S :BEGIN)))
Found (P (AT S :END)) = 190264.481583644
using
    PV/T=P2V2/T2
    (:= (/ (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (T (AT S :BEGIN)))
(/ (* (P (AT S :END)) (V (AT S :END))) (T (AT S :END))))
on
   (T (AT S :BEGIN)) = 308.15
   (P (AT S :BEGIN)) = 200000
   (V (AT S :BEGIN)) = 10
   (T (AT S :END)) = 293.15
   (V (AT S :END)) = 10
;;; Finished <P: HB4.15A>

;;; Answer-for :HB4.15B: -243048.743739333
;;; Answer is correct! Given (-243.7 KJ) =~ -243.048743739333
;;; (NVALUE (Q COOL) -243048.743739333)
Found (V (AT CAN :END)) = 10
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT CAN :END)))
Found (V (AT S :END)) = 10
using equality
    (:= (V (AT CAN :END)) (V (AT S :END)))
Found (V (AT S :BEGIN)) = 10
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT S :BEGIN)))
Found (P (AT S :END)) = 190264.481583644
using
    PV/T=P2V2/T2
    (:= (/ (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (T (AT S :BEGIN)))
(/ (* (P (AT S :END)) (V (AT S :END))) (T (AT S :END))))
on
   (T (AT S :BEGIN)) = 308.15
   (P (AT S :BEGIN)) = 200000
   (V (AT S :BEGIN)) = 10
   (T (AT S :END)) = 293.15
   (V (AT S :END)) = 10
Found (MASS (AT S :END)) = 22.6144446372954
using
    IDEAL-GAS-LAW
    (:= (* (P (AT S :END)) (V (AT S :END))) (* (MASS (AT S :END)) (R
AIR) (T (AT S :END))))
on
   (T (AT S :END)) = 293.15
   (V (AT S :END)) = 10
   (R AIR) = 287
   (P (AT S :END)) = 190264.481583644
```

```
Found (SPEC-U (AT S :END)) = 210041.975
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :END)) (* (CV AIR) (T (AT S :END))))
on
   (T (AT S :END)) = 293.15
   (CV AIR) = 716.5
Found (U (AT S :END)) = 4749982.61514568
using
    SPEC-U-DEFINITION
    (:= (SPEC-U (AT S :END)) (/ (U (AT S :END)) (MASS (AT S :END))))
on
   (SPEC-U (AT S :END)) = 210041.975
   (MASS (AT S :END)) = 22.6144446372954
Found (ENERGY (AT S :END)) = 4749982.61514568
using equality
    (:= (ENERGY (AT S :END)) (U (AT S :END)))
Found (ENERGY-END COOL) = 4749982.61514568
using equality
    (:= (ENERGY-END COOL) (ENERGY (AT S :END)))
Found (MASS (AT S :BEGIN)) = 22.6144446372954
using
    IDEAL-GAS-LAW
    (:= (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (* (MASS (AT S
:BEGIN)) (R AIR) (T (AT S :BEGIN))))
on
   (T (AT S :BEGIN)) = 308.15
   (P (AT S :BEGIN)) = 200000
   (V (AT S :BEGIN)) = 10
   (R AIR) = 287
Found (SPEC-U (AT S :BEGIN)) = 220789.475
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :BEGIN)) (* (CV AIR) (T (AT S :BEGIN))))
on
   (T (AT S :BEGIN)) = 308.15
   (CV AIR) = 716.5
Found (U (AT S :BEGIN)) = 4993031.35888502
using
    SPEC-U-DEFINITION
    (:= (SPEC-U (AT S :BEGIN)) (/ (U (AT S :BEGIN)) (MASS (AT S
:BEGIN))))
on
   (SPEC-U (AT S :BEGIN)) = 220789.475
   (MASS (AT S :BEGIN)) = 22.6144446372954
Found (ENERGY (AT S :BEGIN)) = 4993031.35888502
using equality
    (:= (ENERGY (AT S :BEGIN)) (U (AT S :BEGIN)))
Found (ENERGY-BEGIN COOL) = 4993031.35888502
using equality
    (:= (ENERGY-BEGIN COOL) (ENERGY (AT S :BEGIN)))
Found (Q COOL) = -243048.743739333
using
    CONSERVATION-OF-ENERGY
    (:= (+ (Q COOL) (ENERGY-BEGIN COOL) (ENERGY-INLET COOL)) (+
(ENERGY-END COOL) (ENERGY-OUTLET COOL) (WORK COOL)))
```

```
on
   (WORK COOL) = 0
   (ENERGY-OUTLET COOL) = 0
   (ENERGY-INLET COOL) = 0
   (ENERGY-BEGIN COOL) = 4993031.35888502
   (ENERGY-END COOL) = 4749982.61514568
```
;;; Finished <P: HB4.15B>

4.17 Saturated refrigerant 12 vapor (1 kg) is contained in a rigid canister of volume of 0.01 m^3. Heat transfer occurs until the quality of the refrigerant 12 is 0.5.

(*a*) Sketch the process on a *P*-*v* diagram.

(*b*) Find the initial temperature and pressure in the canister.

(c) Find the final specific enthalpy *h* of the refrigerant 12.

```
(add-problem-description :hb4.17
 :givens '((container (at can :begin))
           (closed (at can :begin))
           (rigid (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (substance-of (at s :begin) refrigerant-12)
           (:not (ideal-gas-substance refrigerant-12))
           (saturated-vapor (at s :begin))

           (nvalue (mass (at S :begin)) 1 kg)
           (nvalue (V (at can :begin)) 0.01 m^3)

           (cooling cool (at s :begin) (at s :end))

           (saturated (at s :end))
           (nvalue (dryness (at s :end)) 0.5)))

(add-problem-goal :hb4.17a
  :description :hb4.17
  :goal '(plot-graph (P spec-v) cool))

(add-problem-goal :hb4.17b
  :description :hb4.17
  :goal '(find (nvalue (P (at s :begin))))
  :answer '(1694.5 kPa))

(add-problem-goal :hb4.17c
  :description :hb4.17
  :goal '(find (nvalue (spec-h (at s :end))))
  :answer '(140.8 kj/kg))


;;; Answer-for :HB4.17B: 1672233.84615385
;;; Answer is correct! Given (1694.5 KPA) =~ 1672.23384615385
```

```
;;; (NVALUE (P (AT S :BEGIN)) 1672233.84615385)
Found (V (AT S :BEGIN)) = 0.01
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT S :BEGIN)))
Found (SPEC-V (AT S :BEGIN)) = 0.01
using
    SPEC-V-DEFINITION
    (:= (SPEC-V (AT S :BEGIN)) (/ (V (AT S :BEGIN)) (MASS (AT S
:BEGIN))))
on
   (MASS (AT S :BEGIN)) = 1
   (V (AT S :BEGIN)) = 0.01
Found (P (AT S :BEGIN)) = 1672233.84615385
using
    SATURATED-TABLE-DRYNESS-SPEC-V-LOOKUP
on
   (DRYNESS (AT S :BEGIN)) = 1
   (SPEC-V (AT S :BEGIN)) = 0.01
```

;;; Finished <P: HB4.17B>

```
;;; Answer-for :HB4.17C: 137388.748743719
;;; Answer is correct! Given (140.8 KJ/KG) =~ 137.388748743719
;;; (NVALUE (SPEC-H (AT S :END)) 137388.748743719)
Found (MASS-BEGIN COOL) = 1
using equality
    (:= (MASS-BEGIN COOL) (MASS (AT S :BEGIN)))
Found (MASS-END COOL) = 1
using
    CONSERVATION-OF-MASS
    (:= (+ (MASS-BEGIN COOL) (MASS-INLET COOL)) (+ (MASS-END COOL)
(MASS-OUTLET COOL)))
on
   (MASS-BEGIN COOL) = 1
   (MASS-OUTLET COOL) = 0
   (MASS-INLET COOL) = 0
Found (MASS (AT S :END)) = 1
using equality
    (:= (MASS-END COOL) (MASS (AT S :END)))
Found (V (AT CAN :END)) = 0.01
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT CAN :END)))
Found (V (AT S :END)) = 0.01
using equality
    (:= (V (AT CAN :END)) (V (AT S :END)))
Found (SPEC-V (AT S :END)) = 0.01
using
    SPEC-V-DEFINITION
    (:= (SPEC-V (AT S :END)) (/ (V (AT S :END)) (MASS (AT S :END))))
on
   (V (AT S :END)) = 0.01
   (MASS (AT S :END)) = 1
Found (SPEC-HG (AT S :END)) = 202433.648241206
using
    SATURATED-TABLE-DRYNESS-SPEC-V-LOOKUP
on
   (DRYNESS (AT S :END)) = 0.5
```

```
   (SPEC-V (AT S :END)) = 0.01
Found (SPEC-HF (AT S :END)) = 72343.8492462312
using
    SATURATED-TABLE-DRYNESS-SPEC-V-LOOKUP
on
   (DRYNESS (AT S :END)) = 0.5
   (SPEC-V (AT S :END)) = 0.01
Found (SPEC-H (AT S :END)) = 137388.748743719
using
    H-SATURATED-STUFF
    (:= (SPEC-H (AT S :END)) (+ (SPEC-HF (AT S :END)) (* (DRYNESS (AT
S :END)) (- (SPEC-HG (AT S :END)) (SPEC-HF (AT S :END))))))
on
   (DRYNESS (AT S :END)) = 0.5
   (SPEC-HF (AT S :END)) = 72343.8492462312
   (SPEC-HG (AT S :END)) = 202433.648241206
;;; Finished <P: HB4.17C>
```

4.21S Water (2 kg) is contained within a piston-cylinder arrangement. See Fig. P4.21. The initial temperature is 105°C, and there are equal masses of liquid and vapor initially. The system is heated to a position where the piston is locked, and then the system is cooled to the saturated vapor state at T = 50°C. Evaluate the work done during the process.

```
(add-problem :hb4.21
 :givens '((piston (at can :begin))
         (static-thermodynamic-stuff (at S :begin))
         (inside (at S :begin) (at can :begin))
         (direction (at can :begin) :up)
         (substance-of (at s :begin) water)

         (nvalue (mass (at S :begin)) 2 kg)
         (nvalue (T (at S :begin)) 105 C)
         (nvalue (dryness (at s :begin)) 0.5)
         (saturated (at s :begin))
         ;; piston is heated and then locked
         (heating htr (at s :begin) (at s :lock))

         (cooling clr (at s :lock) (at s :end))
           (= (P (at s :begin)) (P (at s :lock)))
           (= (spec-v (at s :lock)) (spec-v (at s :end)))
         (saturated-vapor (at s :end))
         (nvalue (T (at s :end)) 50 C)
         )
 :goal '(find (nvalue (work htr)))
 :answer '(2736 kJ)
 )


;;; Answer-for :HB4.21: 2738779.4853295
;;; Answer is correct! Given (2736 KJ) =~ 2738.7794853295
;;; (NVALUE (WORK HTR) 2738779.4853295)
Found (SPEC-VG (AT S :BEGIN)) = 1.42032257093723
```

```
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 378.15
Found (SPEC-VF (AT S :BEGIN)) = 0.00104739438521066
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 378.15
Found (SPEC-V (AT S :BEGIN)) = 0.710684982661222
using
    V-SATURATED-STUFF
    (:= (SPEC-V (AT S :BEGIN)) (+ (SPEC-VF (AT S :BEGIN)) (* (DRYNESS
(AT S :BEGIN)) (- (SPEC-VG (AT S :BEGIN)) (SPEC-VF (AT S :BEGIN))))))
on
   (DRYNESS (AT S :BEGIN)) = 0.5
   (SPEC-VF (AT S :BEGIN)) = 0.00104739438521066
   (SPEC-VG (AT S :BEGIN)) = 1.42032257093723
Found (DENSITY (AT S :BEGIN)) = 1.40709319093167
using equality
    (:= (DENSITY (AT S :BEGIN)) (/ 1 (SPEC-V (AT S :BEGIN))))
Found (V (AT S :BEGIN)) = 1.42136996532244
using
    DENSITY-DEFINITION
    (:= (DENSITY (AT S :BEGIN)) (/ (MASS (AT S :BEGIN)) (V (AT S
:BEGIN))))
on
   (MASS (AT S :BEGIN)) = 2
   (DENSITY (AT S :BEGIN)) = 1.40709319093167
Found (MASS-BEGIN HTR) = 2
using equality
    (:= (MASS-BEGIN HTR) (MASS (AT S :BEGIN)))
Found (MASS-END HTR) = 2
using
    CONSERVATION-OF-MASS
    (:= (+ (MASS-BEGIN HTR) (MASS-INLET HTR)) (+ (MASS-END HTR)
(MASS-OUTLET HTR)))
on
   (MASS-BEGIN HTR) = 2
   (MASS-OUTLET HTR) = 0
   (MASS-INLET HTR) = 0
Found (MASS (AT S :LOCK)) = 2
using equality
    (:= (MASS-END HTR) (MASS (AT S :LOCK)))
Found (SPEC-VG (AT S :END)) = 12.0455148514852
using
    SATURATED-TABLE-T
on
   (T (AT S :END)) = 323.15
Found (SPEC-V (AT S :END)) = 12.0455148514852
using equality
    (:= (SPEC-V (AT S :END)) (SPEC-VG (AT S :END)))
Found (SPEC-V (AT S :LOCK)) = 12.0455148514852
using equality
    (:= (SPEC-V (AT S :END)) (SPEC-V (AT S :LOCK)))
Found (V (AT S :LOCK)) = 24.0910297029703
```

```
using
    SPEC-V-DEFINITION
    (:= (SPEC-V (AT S :LOCK)) (/ (V (AT S :LOCK)) (MASS (AT S
:LOCK))))
on
   (SPEC-V (AT S :LOCK)) = 12.0455148514852
   (MASS (AT S :LOCK)) = 2
Found (P (AT S :BEGIN)) = 120812.553740327
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 378.15
Found (P (AT S :LOCK)) = 120812.553740327
using equality
    (:= (P (AT S :BEGIN)) (P (AT S :LOCK)))
Found (WORK HTR) = 2738779.4853295
using
    WORK=PDV-LINEAR
    (:= (WORK HTR) (* (* (+ (P (AT S :BEGIN)) (P (AT S :LOCK))) 0.5)
(- (V (AT S :LOCK)) (V (AT S :BEGIN)))))
on
   (P (AT S :BEGIN)) = 120812.553740327
   (P (AT S :LOCK)) = 120812.553740327
   (V (AT S :LOCK)) = 24.0910297029703
   (V (AT S :BEGIN)) = 1.42136996532244
;;; Finished <P: HB4.21>
```

4.27S Saturated water vapor at 200°C is contained in a cylinder fitted with a piston. The initial volume of the steam is 0.05 m^3. The H_20 is then compressed in an isothermal process until the quality is 20 percent. Determine the total work done in kilojoules on the system during this process.

```
(add-problem :hb4.27
 :givens '((piston (at can :begin))
         (static-thermodynamic-stuff (at S :begin))
         (inside (at S :begin) (at can :begin))
         (direction (at can :begin) :up)
         (substance-of (at s :begin) water)

         (nvalue (T (at S :begin)) 200 C)
         (nvalue (V (at S :begin)) 0.05 m^3)
           (saturated-vapor (at s :begin))

         (compressing cmp (at s :begin) (at s :end))
         (isothermal cmp)

         (saturated (at s :end))
         (nvalue (dryness (at s :end)) 0.20))
 :goal '(find (nvalue (work cmp)))
 :answer '(-61.33 kj))

;;; Answer-for :HB4.27: -61582.7094385997
;;; Answer is correct! Given (-61.33 KJ) =~ -61.5827094385997
;;; (NVALUE (WORK CMP) -61582.7094385997)
```

```
Found (SPEC-VG (AT S :BEGIN)) = 0.127320367936925
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 473.15
Found (SPEC-V (AT S :BEGIN)) = 0.127320367936925
using equality
    (:= (SPEC-V (AT S :BEGIN)) (SPEC-VG (AT S :BEGIN)))
Found (MASS (AT S :BEGIN)) = 0.392710143790742
using
    SPEC-V-DEFINITION
    (:= (SPEC-V (AT S :BEGIN)) (/ (V (AT S :BEGIN)) (MASS (AT S
:BEGIN))))
on
   (V (AT S :BEGIN)) = 0.05
   (SPEC-V (AT S :BEGIN)) = 0.127320367936925
Found (MASS-BEGIN CMP) = 0.392710143790742
using equality
    (:= (MASS-BEGIN CMP) (MASS (AT S :BEGIN)))
Found (MASS-END CMP) = 0.392710143790742
using
    CONSERVATION-OF-MASS
    (:= (+ (MASS-BEGIN CMP) (MASS-INLET CMP)) (+ (MASS-END CMP)
(MASS-OUTLET CMP)))
on
   (MASS-OUTLET CMP) = 0
   (MASS-INLET CMP) = 0
   (MASS-BEGIN CMP) = 0.392710143790742
Found (MASS (AT S :END)) = 0.392710143790742
using equality
    (:= (MASS-END CMP) (MASS (AT S :END)))
Found (T (AT S :END)) = 473.15
using equality
    (:= (T (AT S :BEGIN)) (T (AT S :END)))
Found (SPEC-VG (AT S :END)) = 0.127320367936925
using
    SATURATED-TABLE-T
on
   (T (AT S :END)) = 473.15
Found (SPEC-VF (AT S :END)) = 0.00115641513797635
using
    SATURATED-TABLE-T
on
   (T (AT S :END)) = 473.15
Found (SPEC-V (AT S :END)) = 0.0263892056977661
using
    V-SATURATED-STUFF
    (:= (SPEC-V (AT S :END)) (+ (SPEC-VF (AT S :END)) (* (DRYNESS (AT
S :END)) (- (SPEC-VG (AT S :END)) (SPEC-VF (AT S :END))))))
on
   (DRYNESS (AT S :END)) = 0.2
   (SPEC-VF (AT S :END)) = 0.00115641513797635
   (SPEC-VG (AT S :END)) = 0.127320367936925
Found (V (AT S :END)) = 0.0103633087640932
using
    SPEC-V-DEFINITION
```

```
    (:= (SPEC-V (AT S :END)) (/ (V (AT S :END)) (MASS (AT S :END))))
on
   (SPEC-V (AT S :END)) = 0.0263892056977661
   (MASS (AT S :END)) = 0.392710143790742
Found (P (AT S :END)) = 1553679.36925098
using
    SATURATED-TABLE-T
on
   (T (AT S :END)) = 473.15
Found (P (AT S :BEGIN)) = 1553679.36925098
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 473.15
Found (WORK CMP) = -61582.7094385997
using
    WORK=PDV-LINEAR
    (:= (WORK CMP) (* (* (+ (P (AT S :BEGIN)) (P (AT S :END))) 0.5)
(- (V (AT S :END)) (V (AT S :BEGIN)))))
on
   (V (AT S :BEGIN)) = 0.05
   (P (AT S :BEGIN)) = 1553679.36925098
   (P (AT S :END)) = 1553679.36925098
   (V (AT S :END)) = 0.0103633087640932
;;; Finished <P: HB4.27>
```

4.29S Water is cooled in a closed rigid vessel from a temperature of 600°C and pressure of 4.0 MPa to a temperature of l00°C.

(*a*) How much work is done?

(b) What is the change in pressure?

```
(add-problem-description :hb4.29
 :givens '((container (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (rigid (at can :begin))
           (closed (at can :begin))
           (substance-of (at s :begin) water)
           (nvalue (T (at s :begin)) 600 C)
           (nvalue (P (at s :begin)) 4 MPa)
           (cooling cool (at s :begin) (at s :end))
           (nvalue (T (at s :end)) 100 C)))

(add-problem-goal :hb4.29a
  :description :hb4.29
  :goal '(find (nvalue (work cool)))
  :answer '(0 kJ))

(add-problem-goal :hb4.29b
  :description :hb4.29
  :goal '(find (nvalue (delta-p cool)))
  :answer '(-3.899 MPa))
```

```
;;; Answer-for :HB4.29B: -3898630.44287309
;;; Answer is correct! Given (-3.899 MPA) =~ -3.89863044287309
;;; (NVALUE (DELTA-P COOL) -3898630.44287309)
Found (P (AT S :END)) = 101369.557126907
using
    SATURATED-TABLE-T
on
   (T (AT S :END)) = 373.15
Found (DELTA-P COOL) = -3898630.44287309
using
    DELTA-P-DEFINITION
    (:= (DELTA-P COOL) (- (P (AT S :END)) (P (AT S :BEGIN))))
on
   (P (AT S :BEGIN)) = 4000000
   (P (AT S :END)) = 101369.557126907
;;; Finished <P: HB4.29B>
```

4.31S Water is contained in a piston-cylinder device, and the piston is free to move. Initially the H_2O is at a pressure of 1.0 MPa and a temperature of 600°C. The H_2O is cooled until the specific volume is 0.205 m^3. Determine the work done on the system in kilojoules per kilogram and the mass of H_2O if the total work done on the system is 30 kJ.

```
(add-problem-description :hb4.31
 :givens '((piston (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (direction (at can :begin) :up)
           (substance-of (at s :begin) water)
           (nvalue (T (at S :begin)) 600 C)
           (nvalue (P (at S :begin)) 1 MPa)
           (cooling cool (at s :begin) (at s :end))
           (nvalue (spec-v (at s :end)) 0.205 m^3/kg)))

(add-problem-goal :hb4.31a
  :description :hb4.31
  :goal '(find (nvalue (spec-work cool)))
  :answer '(-196.1 kJ/kg))

(add-problem-goal :hb4.31b
  :description :hb4.31
  :extras '((nvalue (work cool) -30 kJ))
  :goal '(find (nvalue (mass (at s :begin))))
  :answer '(0.153 kg))

;;; Answer-for :HB4.31A: -196090.0
;;; Answer is correct! Given (-196.1 KJ/KG) =~ -196.09
;;; (NVALUE (SPEC-WORK COOL) -196090.0)
Found (SPEC-V (AT S :BEGIN)) = 0.40109
using
    SUPERHEATED-P-T
on
   (T (AT S :BEGIN)) = 873.15
```

```
   (P (AT S :BEGIN)) = 1000000
Found (SPEC-WORK COOL) = -196090.0
using
    SPEC-WORK=PDV-ISOBARIC
    (:= (SPEC-WORK COOL) (* (P (AT S :BEGIN)) (- (SPEC-V (AT S :END))
(SPEC-V (AT S :BEGIN)))))
on
   (P (AT S :BEGIN)) = 1000000
   (SPEC-V (AT S :END)) = 0.205
   (SPEC-V (AT S :BEGIN)) = 0.40109
```

;;; Finished <P: HB4.31A>

```
;;; Answer-for :HB4.31B: 0.152990973532562
;;; Answer is correct! Given (0.153 KG) =~ 0.152990973532562
;;; (NVALUE (MASS (AT S :BEGIN)) 0.152990973532562)
Found (SPEC-V (AT S :BEGIN)) = 0.40109
using
    SUPERHEATED-P-T
on
   (T (AT S :BEGIN)) = 873.15
   (P (AT S :BEGIN)) = 1000000
Found (SPEC-WORK COOL) = -196090.0
using
    SPEC-WORK=PDV-ISOBARIC
    (:= (SPEC-WORK COOL) (* (P (AT S :BEGIN)) (- (SPEC-V (AT S :END))
(SPEC-V (AT S :BEGIN)))))
on
   (P (AT S :BEGIN)) = 1000000
   (SPEC-V (AT S :END)) = 0.205
   (SPEC-V (AT S :BEGIN)) = 0.40109
Found (MASS-BEGIN COOL) = 0.152990973532562
using
    WORK-DEFINITION
    (:= (WORK COOL) (* (SPEC-WORK COOL) (MASS-BEGIN COOL)))
on
   (WORK COOL) = -30000
   (SPEC-WORK COOL) = -196090.0
Found (MASS (AT S :BEGIN)) = 0.152990973532562
using equality
    (:= (MASS-BEGIN COOL) (MASS (AT S :BEGIN)))
```

;;; Finished <P: HB4.31B>

4.33 A rigid aluminum container with a volume of 0.755 contains 30 kg of water at an initial pressure and temperature of 25.033 kPa and 65°C. If the manufacturer's specifications state that the container will rupture at a pressure of 20.0 MPa, what is the total heat transfer necessary to rupture the container? Show the process on a *T*-*v* diagram.

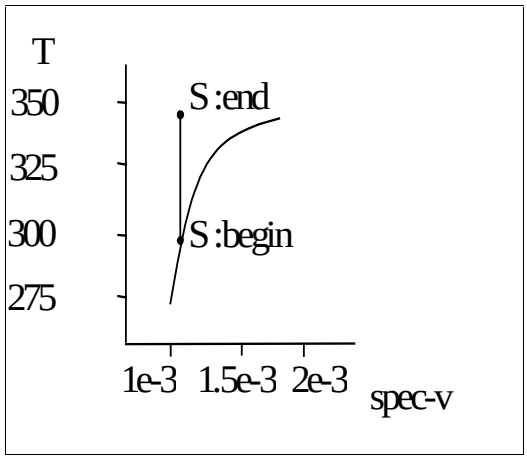
```
(add-problem-description :hb4.33
 :givens '((container (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
```

```
            (rigid (at can :begin))
            (closed (at can :begin))
            (substance-of (at s :begin) water)
            (nvalue (V (at can :begin)) 0.755 m^3)
            (nvalue (mass (at s :begin)) 30 kg)
            (nvalue (P (at s :begin)) 25.033 kPa)
            (nvalue (T (at s :begin)) 65 C)
            (heating htr (at s :begin) (at s :end))
            (nvalue (P (at s :end)) 20.0 MPa)
            (:not (work-device htr))))

(add-problem-goal :hb4.33a
  :description :hb4.33
  :goal '(find (nvalue (q htr)))
  :answer '(1.022e8 J))


(add-problem-goal :hb4.33b
  :description :hb4.33
  :goal '(plot-graph (T spec-v) htr))


;;; Answer-for :HB4.33A: 1.02186704735047E8
;;; Answer is correct! Given (1.022E8 J) =~ 1.02186704735047E8
;;; (NVALUE (Q HTR) 1.02186704735047E8)
Found (MASS-BEGIN HTR) = 30
using equality
    (:= (MASS-BEGIN HTR) (MASS (AT S :BEGIN)))
Found (MASS-END HTR) = 30
using
    CONSERVATION-OF-MASS
    (:= (+ (MASS-BEGIN HTR) (MASS-INLET HTR)) (+ (MASS-END HTR)
(MASS-OUTLET HTR)))
on
   (MASS-BEGIN HTR) = 30
   (MASS-OUTLET HTR) = 0
   (MASS-INLET HTR) = 0
Found (MASS (AT S :END)) = 30
using equality
    (:= (MASS-END HTR) (MASS (AT S :END)))
Found (V (AT CAN :END)) = 0.755
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT CAN :END)))
Found (V (AT S :END)) = 0.755
using equality
    (:= (V (AT CAN :END)) (V (AT S :END)))
Found (SPEC-V (AT S :END)) = 0.0251666666666667
using
    SPEC-V-DEFINITION
    (:= (SPEC-V (AT S :END)) (/ (V (AT S :END)) (MASS (AT S :END))))
on
   (V (AT S :END)) = 0.755
   (MASS (AT S :END)) = 30
Found (SPEC-U (AT S :END)) = 3687177.51762336
using
    SUPERHEATED-P-SPEC-V
```

```
on
   (P (AT S :END)) = 2.0E7
   (SPEC-V (AT S :END)) = 0.0251666666666667
Found (U (AT S :END)) = 1.10615325528701E8
using
    SPEC-U-DEFINITION
    (:= (SPEC-U (AT S :END)) (/ (U (AT S :END)) (MASS (AT S :END))))
on
   (MASS (AT S :END)) = 30
   (SPEC-U (AT S :END)) = 3687177.51762336
Found (ENERGY (AT S :END)) = 1.10615325528701E8
using equality
    (:= (ENERGY (AT S :END)) (U (AT S :END)))
Found (ENERGY-END HTR) = 1.10615325528701E8
using equality
    (:= (ENERGY-END HTR) (ENERGY (AT S :END)))
Found (SPEC-VG (AT S :BEGIN)) = 6.20008301886793
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 338.15
Found (SPEC-VF (AT S :BEGIN)) = 0.00101986151427189
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 338.15
Found (V (AT S :BEGIN)) = 0.755
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT S :BEGIN)))
Found (SPEC-V (AT S :BEGIN)) = 0.0251666666666667
using
    SPEC-V-DEFINITION
    (:= (SPEC-V (AT S :BEGIN)) (/ (V (AT S :BEGIN)) (MASS (AT S
:BEGIN))))
on
   (V (AT S :BEGIN)) = 0.755
   (MASS (AT S :BEGIN)) = 30
Found (DRYNESS (AT S :BEGIN)) = 0.00389523457649412
using
    V-SATURATED-STUFF
    (:= (SPEC-V (AT S :BEGIN)) (+ (SPEC-VF (AT S :BEGIN)) (* (DRYNESS
(AT S :BEGIN)) (- (SPEC-VG (AT S :BEGIN)) (SPEC-VF (AT S :BEGIN))))))
on
   (SPEC-V (AT S :BEGIN)) = 0.0251666666666667
   (SPEC-VF (AT S :BEGIN)) = 0.00101986151427189
   (SPEC-VG (AT S :BEGIN)) = 6.20008301886793
Found (SPEC-UG (AT S :BEGIN)) = 2615884.73633285
using
    SATURATED-TABLE-DRYNESS-SPEC-V-LOOKUP
on
   (SPEC-V (AT S :BEGIN)) = 0.0251666666666667
   (DRYNESS (AT S :BEGIN)) = 0.00389523457649412
Found (SPEC-UF (AT S :BEGIN)) = 271823.35752298
using
    SATURATED-TABLE-T
on
```

```
   (T (AT S :BEGIN)) = 338.15
Found (SPEC-U (AT S :BEGIN)) = 280954.026455145
using
    U-SATURATED-STUFF
    (:= (SPEC-U (AT S :BEGIN)) (+ (SPEC-UF (AT S :BEGIN)) (* (DRYNESS
(AT S :BEGIN)) (- (SPEC-UG (AT S :BEGIN)) (SPEC-UF (AT S :BEGIN))))))
on
   (SPEC-UF (AT S :BEGIN)) = 271823.35752298
   (DRYNESS (AT S :BEGIN)) = 0.00389523457649412
   (SPEC-UG (AT S :BEGIN)) = 2615884.73633285
Found (U (AT S :BEGIN)) = 8428620.79365434
using
    SPEC-U-DEFINITION
    (:= (SPEC-U (AT S :BEGIN)) (/ (U (AT S :BEGIN)) (MASS (AT S
:BEGIN))))
on
   (MASS (AT S :BEGIN)) = 30
   (SPEC-U (AT S :BEGIN)) = 280954.026455145
Found (ENERGY (AT S :BEGIN)) = 8428620.79365434
using equality
    (:= (ENERGY (AT S :BEGIN)) (U (AT S :BEGIN)))
Found (ENERGY-BEGIN HTR) = 8428620.79365434
using equality
    (:= (ENERGY-BEGIN HTR) (ENERGY (AT S :BEGIN)))
Found (Q HTR) = 1.02186704735047E8
using
    CONSERVATION-OF-ENERGY
    (:= (+ (Q HTR) (ENERGY-BEGIN HTR) (ENERGY-INLET HTR)) (+ (ENERGY-
END HTR) (ENERGY-OUTLET HTR) (WORK HTR)))
on
   (WORK HTR) = 0
   (ENERGY-OUTLET HTR) = 0
   (ENERGY-INLET HTR) = 0
   (ENERGY-BEGIN HTR) = 8428620.79365434
   (ENERGY-END HTR) = 1.10615325528701E8
```

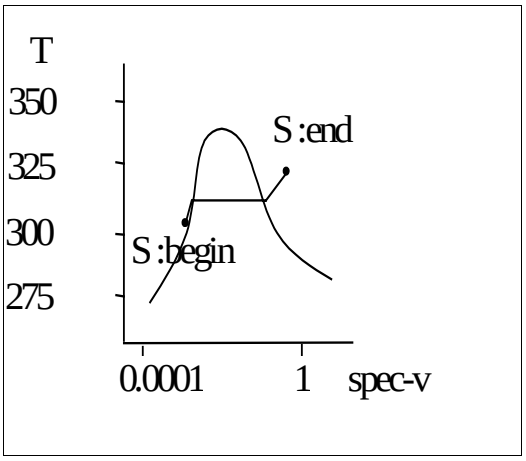
;;; Finished <P: HB4.33A>



4.35 A vertical frictionless piston-cylinder device containing water has an initial temperature and pressure of 10°C and 40 N/cm^2. There is a heat transfer to the cylinder until the final temperature is 550°C. What is the final specific volume, and how much heat transfer is added? Show the process on a *T*-*v* diagram.

```
(add-problem-description :hb4.35
 :givens '((piston (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (direction (at can :begin) :up)
           (substance-of (at s :begin) water)
           (nvalue (T (at S :begin)) 10 C)
           (nvalue (P (at S :begin)) 40 N/cm^2)
           (contained-process htr (at s :begin) (at s :end))
           (nvalue (T (at s :end)) 550 C)))

(add-problem-goal :hb4.35a
  :description :hb4.35
  :goal '(find (nvalue (spec-q htr)))
  :answer '(3550.71 kJ/kg))

(add-problem-goal :hb4.35b
  :description :hb4.35
  :goal '(plot-graph (T spec-v) htr))


;;; Answer-for :HB4.35A: 3550727.453
;;; Answer is correct! Given (3550.71 KJ/KG) =~ 3550.727453
;;; (NVALUE (SPEC-Q HTR) 3550727.453)
Found (SPEC-U (AT S :BEGIN)) = 41972.5
using
    SUBCOOLED-P-T
on
   (T (AT S :BEGIN)) = 283.15
   (P (AT S :BEGIN)) = 400000
Found (SPEC-V (AT S :BEGIN)) = 0.0010001175
using
    SUBCOOLED-T-SPEC-U
on
   (T (AT S :BEGIN)) = 283.15
   (SPEC-U (AT S :BEGIN)) = 41972.5
Found (P (AT S :END)) = 400000
using equality
    (:= (P (AT S :BEGIN)) (P (AT S :END)))
Found (SPEC-U (AT S :END)) = 3214100.0
using
    SUPERHEATED-P-T
on
   (T (AT S :END)) = 823.15
   (P (AT S :END)) = 400000
Found (SPEC-V (AT S :END)) = 0.9475
using
    SUPERHEATED-T-SPEC-U
on
   (T (AT S :END)) = 823.15
```

```
   (SPEC-U (AT S :END)) = 3214100.0
Found (SPEC-WORK HTR) = 378599.953
using
    SPEC-WORK=PDV-ISOBARIC
    (:= (SPEC-WORK HTR) (* (P (AT S :BEGIN)) (- (SPEC-V (AT S :END))
(SPEC-V (AT S :BEGIN)))))
on
   (P (AT S :BEGIN)) = 400000
   (SPEC-V (AT S :END)) = 0.9475
   (SPEC-V (AT S :BEGIN)) = 0.0010001175
Found (SPEC-ENERGY (AT S :END)) = 3214100.0
using equality
    (:= (SPEC-ENERGY (AT S :END)) (SPEC-U (AT S :END)))
Found (SPEC-ENERGY-END HTR) = 3214100.0
using equality
    (:= (SPEC-ENERGY-END HTR) (SPEC-ENERGY (AT S :END)))
Found (SPEC-ENERGY (AT S :BEGIN)) = 41972.5
using equality
    (:= (SPEC-ENERGY (AT S :BEGIN)) (SPEC-U (AT S :BEGIN)))
Found (SPEC-ENERGY-BEGIN HTR) = 41972.5
using equality
    (:= (SPEC-ENERGY-BEGIN HTR) (SPEC-ENERGY (AT S :BEGIN)))
Found (SPEC-Q HTR) = 3550727.453
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q HTR) (SPEC-ENERGY-BEGIN HTR) (SPEC-ENERGY-INLET
HTR)) (+ (SPEC-ENERGY-END HTR) (SPEC-ENERGY-OUTLET HTR) (SPEC-WORK
HTR)))
on
   (SPEC-ENERGY-OUTLET HTR) = 0
   (SPEC-ENERGY-INLET HTR) = 0
   (SPEC-ENERGY-BEGIN HTR) = 41972.5
   (SPEC-ENERGY-END HTR) = 3214100.0
   (SPEC-WORK HTR) = 378599.953
;;; Finished <P: HB4.35A>
```



4.37 Water (1 kg) is contained in a vertical frictionless piston-cylinder device. The mass of the piston is such that the H_2O exists at a pressure of 20.0 MPa and a

temperature of 850°C. There is a heat transfer from the device until the piston just rests on stops, at which time the volume inside the cylinder is 1.560 x 10^{-3} m^3. Determine the total work and heat transferred for this process, and show the process on a *T-v* diagram.

```
(add-problem-description :hb4.37
 :givens '((piston (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (direction (at can :begin) :up)
           (piston-stop-for (at can :begin) (at stop :begin))
           (under (at stop :begin) (top (at can :begin)))
           (substance-of (at s :begin) water)
           (nvalue (mass (at S :begin)) 1 kg)
           (nvalue (P (at s :begin)) 20 Mpa)
           (nvalue (T (at S :begin)) 850 C)
           (contained-process cool (at s :begin) (at s :end))
           (nvalue (V (at s :end)) 0.001560 m^3)
           (resting (at stop :end) (at b :end))))

(add-problem-goal :hb4.37a
  :description :hb4.37
  :goal '(find (nvalue (work cool)))
  :answer '(-473.0 kJ))

(add-problem-goal :hb4.37b
  :description :hb4.37
  ;; our double-interpolation from tables is bad,
  ;; we have to with what we find from the tables!
  :goal '(find (nvalue (Q cool)))
  :answer '(-3389.4 kJ))


;;; Answer-for :HB4.37A: -472940.0
;;; Answer is correct! Given (-473.0 KJ) =~ -472.94
;;; (NVALUE (WORK COOL) -472940.0)
Found (SPEC-V (AT S :BEGIN)) = 0.025207
using
    SUPERHEATED-P-T
on
   (P (AT S :BEGIN)) = 20000000
   (T (AT S :BEGIN)) = 1123.15
Found (V (AT S :BEGIN)) = 0.025207
using
    SPEC-V-DEFINITION
    (:= (SPEC-V (AT S :BEGIN)) (/ (V (AT S :BEGIN)) (MASS (AT S
:BEGIN))))
on
   (MASS (AT S :BEGIN)) = 1
   (SPEC-V (AT S :BEGIN)) = 0.025207
Found (WORK COOL) = -472940.0
using
    WORK=PDV-ISOBARIC
    (:= (WORK COOL) (* (P (AT S :BEGIN)) (- (V (AT S :END)) (V (AT S
:BEGIN)))))
```

```
on
   (P (AT S :BEGIN)) = 20000000
   (V (AT S :END)) = 0.00156
   (V (AT S :BEGIN)) = 0.025207
```
;;; Finished <P: HB4.37A>

```
;;; Answer-for :HB4.37B: -3389330.99880465
;;; Answer is correct! Given (-3389.4 KJ) =~ -3389.33099880465
;;; (NVALUE (Q COOL) -3389330.99880465)
Found (SPEC-U (AT S :BEGIN)) = 3690300.0
using
    SUPERHEATED-P-T
on
   (P (AT S :BEGIN)) = 20000000
   (T (AT S :BEGIN)) = 1123.15
Found (SPEC-V (AT S :BEGIN)) = 0.025207
using
    SUPERHEATED-T-SPEC-U
on
   (T (AT S :BEGIN)) = 1123.15
   (SPEC-U (AT S :BEGIN)) = 3690300.0
Found (DENSITY (AT S :BEGIN)) = 39.6715198159242
using equality
    (:= (DENSITY (AT S :BEGIN)) (/ 1 (SPEC-V (AT S :BEGIN))))
Found (V (AT S :BEGIN)) = 0.025207
using
    DENSITY-DEFINITION
    (:= (DENSITY (AT S :BEGIN)) (/ (MASS (AT S :BEGIN)) (V (AT S
:BEGIN))))
on
   (MASS (AT S :BEGIN)) = 1
   (DENSITY (AT S :BEGIN)) = 39.6715198159242
Found (WORK COOL) = -472940.0
using
    WORK=PDV-ISOBARIC
    (:= (WORK COOL) (* (P (AT S :BEGIN)) (- (V (AT S :END)) (V (AT S
:BEGIN)))))
on
   (P (AT S :BEGIN)) = 20000000
   (V (AT S :END)) = 0.00156
   (V (AT S :BEGIN)) = 0.025207
Found (MASS-BEGIN COOL) = 1
using equality
    (:= (MASS-BEGIN COOL) (MASS (AT S :BEGIN)))
Found (MASS-END COOL) = 1
using
    CONSERVATION-OF-MASS
    (:= (+ (MASS-BEGIN COOL) (MASS-INLET COOL)) (+ (MASS-END COOL)
(MASS-OUTLET COOL)))
on
   (MASS-BEGIN COOL) = 1
   (MASS-OUTLET COOL) = 0
   (MASS-INLET COOL) = 0
Found (MASS (AT S :END)) = 1
using equality
    (:= (MASS-END COOL) (MASS (AT S :END)))
```

```
Found (SPEC-V (AT S :END)) = 0.00156
using
    SPEC-V-DEFINITION
    (:= (SPEC-V (AT S :END)) (/ (V (AT S :END)) (MASS (AT S :END))))
on
   (V (AT S :END)) = 0.00156
   (MASS (AT S :END)) = 1
Found (P (AT S :END)) = 20000000
using equality
    (:= (P (AT S :BEGIN)) (P (AT S :END)))
Found (SPEC-U (AT S :END)) = 773909.001195352
using
    SUBCOOLED-P-SPEC-V
on
   (P (AT S :END)) = 20000000
   (SPEC-V (AT S :END)) = 0.00156
Found (U (AT S :END)) = 773909.001195352
using
    SPEC-U-DEFINITION
    (:= (SPEC-U (AT S :END)) (/ (U (AT S :END)) (MASS (AT S :END))))
on
   (MASS (AT S :END)) = 1
   (SPEC-U (AT S :END)) = 773909.001195352
Found (ENERGY (AT S :END)) = 773909.001195352
using equality
    (:= (ENERGY (AT S :END)) (U (AT S :END)))
Found (ENERGY-END COOL) = 773909.001195352
using equality
    (:= (ENERGY-END COOL) (ENERGY (AT S :END)))
Found (U (AT S :BEGIN)) = 3690300.0
using
    SPEC-U-DEFINITION
    (:= (SPEC-U (AT S :BEGIN)) (/ (U (AT S :BEGIN)) (MASS (AT S
:BEGIN))))
on
   (MASS (AT S :BEGIN)) = 1
   (SPEC-U (AT S :BEGIN)) = 3690300.0
Found (ENERGY (AT S :BEGIN)) = 3690300.0
using equality
    (:= (ENERGY (AT S :BEGIN)) (U (AT S :BEGIN)))
Found (ENERGY-BEGIN COOL) = 3690300.0
using equality
    (:= (ENERGY-BEGIN COOL) (ENERGY (AT S :BEGIN)))
Found (Q COOL) = -3389330.99880465
using
    CONSERVATION-OF-ENERGY
    (:= (+ (Q COOL) (ENERGY-BEGIN COOL) (ENERGY-INLET COOL)) (+
(ENERGY-END COOL) (ENERGY-OUTLET COOL) (WORK COOL)))
on
   (ENERGY-OUTLET COOL) = 0
   (ENERGY-INLET COOL) = 0
   (ENERGY-BEGIN COOL) = 3690300.0
   (ENERGY-END COOL) = 773909.001195352
   (WORK COOL) = -472940.0
```

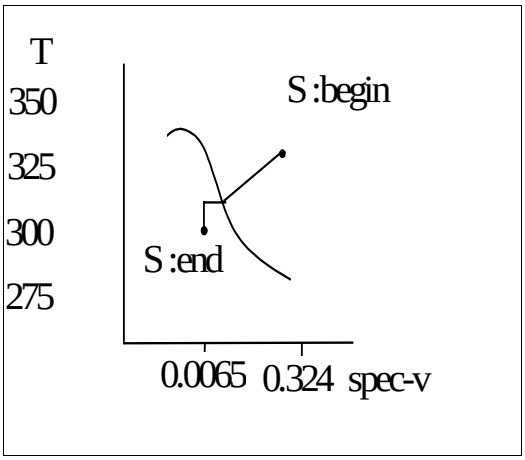
;;; Finished <P: HB4.37B>

4.39 Water is contained in the frictionless piston-cylinder device shown. The H_2O is cooled from an initial temperature of 300°C and pressure of 0.8 MPa to a final pressure of 0.06 MPa. Plot and label the processes on a *T-v* diagram. Determine (*a*) the mass of the H_2O, and (*b*) the total work done in joules.

```
(add-problem-description :hb4.39
 :givens '((piston (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (direction (at can :begin) :up)
           (substance-of (at s :begin) water)
           (circular-cylinder (at can :begin))
           (nvalue (radius (top (at can :begin))) 0.35 m)
           (nvalue (height (at can :begin)) 0.40 m)
           (nvalue (P (at s :begin)) 0.8 Mpa)
           (nvalue (T (at S :begin)) 300 C)
           (contained-process cool (at s :begin) (at s :end))
           (nvalue (height (at can :end)) 0.08 m)
           (nvalue (P (at s :end)) 0.06 Mpa)))

(add-problem-goal :hb4.39a
  :description :hb4.39
  :goal '(find (nvalue (mass (at s :begin))))
  :answer '(0.475 kg))

(add-problem-goal :hb4.39b
  :description :hb4.39
  :goal '(find (nvalue (work cool)))
  :answer '(-98.53 kJ))

(add-problem-goal :hb4.39c
  :description :hb4.39
  :goal '(plot-graph (T spec-v) cool))


;;; Answer-for :HB4.39A: 0.474970811557852
;;; Answer is correct! Given (0.475 KG) =~ 0.474970811557852
;;; (NVALUE (MASS (AT S :BEGIN)) 0.474970811557852)
Found (AREA (TOP (AT CAN :BEGIN))) = 0.38484510006475
using equality
    (:= (AREA (TOP (AT CAN :BEGIN))) (* PI (RADIUS (TOP (AT CAN
:BEGIN))) (RADIUS (TOP (AT CAN :BEGIN)))))
Found (V (AT CAN :BEGIN)) = 0.1539380400259
using
    V-OF-CYLINDER
    (:= (V (AT CAN :BEGIN)) (* (AREA (TOP (AT CAN :BEGIN))) (HEIGHT
(AT CAN :BEGIN))))
on
   (HEIGHT (AT CAN :BEGIN)) = 0.4
   (AREA (TOP (AT CAN :BEGIN))) = 0.38484510006475
Found (V (AT S :BEGIN)) = 0.1539380400259
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT S :BEGIN)))
Found (SPEC-V (AT S :BEGIN)) = 0.3241
using
```

```
    SUPERHEATED-P-T
on
   (P (AT S :BEGIN)) = 800000.0
   (T (AT S :BEGIN)) = 573.15
Found (MASS (AT S :BEGIN)) = 0.474970811557852
using
    SPEC-V-DEFINITION
    (:= (SPEC-V (AT S :BEGIN)) (/ (V (AT S :BEGIN)) (MASS (AT S
:BEGIN))))
on
   (SPEC-V (AT S :BEGIN)) = 0.3241
   (V (AT S :BEGIN)) = 0.1539380400259
```

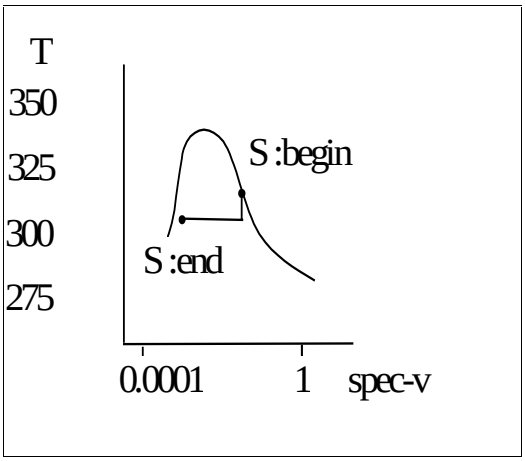
;;; Finished <P: HB4.39A>



4.41 A piston-cylinder device with one set of stops has dimensions as shown. The piston is free to move. The H_2O inside is initially a saturated vapor at 270°C. It is cooled until half the mass is a liquid. The piston requires a pressure of 5.4987 MPa to support it. Draw and label the processes on a *T-v* diagram. Determine (*a*) the initial and final mass of the H_2O and (*b*) the total work done, in kilojoules.

```
(add-problem-description :hb4.41
  :givens '((piston (at can :begin))
            (dual-thermodynamic-stuff (at S :begin))
            (dual-thermodynamic-stuff (at S :end))
            (inside (at S :begin) (at can :begin))
            (direction (at can :begin) :up)
            (substance-of (at s :begin) water)
            (saturated-vapor (at s :begin))
            (nvalue (T (at S :begin)) 270 C)
            (nvalue (P (at S :begin)) 5.4987 Mpa)
            (nvalue (area (top (at can :begin))) 0.00499 m^2)
            (nvalue (height (at can :begin)) 0.10 m)
            (cooling cool (at s :begin) (at s :end))
            (nvalue (dryness (at s :end)) 0.5)))
```

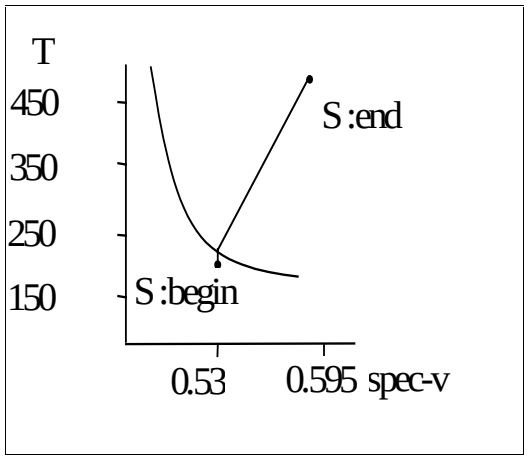
```
(add-problem-goal :hb4.41a
  :description :hb4.41
  :goal '(find (nvalue (mass (at s :begin))))
  :answer '(0.014 kg))

(add-problem-goal :hb4.41b
  :description :hb4.41
  :goal '(find (nvalue (work cool)))
  :answer '(-1.322 kJ))


;;; Answer-for :HB4.41A: 0.0140166183704778
;;; Answer is correct! Given (0.014 KG) =~ 0.0140166183704778
;;; (NVALUE (MASS (AT S :BEGIN)) 0.0140166183704778)
Found (V (AT CAN :BEGIN)) = 4.99E-4
using
    V-OF-CYLINDER
    (:= (V (AT CAN :BEGIN)) (* (AREA (TOP (AT CAN :BEGIN))) (HEIGHT
(AT CAN :BEGIN))))
on
   (AREA (TOP (AT CAN :BEGIN))) = 0.00499
   (HEIGHT (AT CAN :BEGIN)) = 0.1
Found (V (AT S :BEGIN)) = 4.99E-4
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT S :BEGIN)))
Found (SPEC-VG (AT S :BEGIN)) = 0.0356005982905983
using
    SATURATED-TABLE-T
on
   (T (AT S :BEGIN)) = 543.15
Found (SPEC-V (AT S :BEGIN)) = 0.0356005982905983
using equality
    (:= (SPEC-V (AT S :BEGIN)) (SPEC-VG (AT S :BEGIN)))
Found (DENSITY (AT S :BEGIN)) = 28.0894155720998
using equality
    (:= (DENSITY (AT S :BEGIN)) (/ 1 (SPEC-V (AT S :BEGIN))))
Found (MASS (AT S :BEGIN)) = 0.0140166183704778
using
    DENSITY-DEFINITION
    (:= (DENSITY (AT S :BEGIN)) (/ (MASS (AT S :BEGIN)) (V (AT S
:BEGIN))))
on
   (DENSITY (AT S :BEGIN)) = 28.0894155720998
   (V (AT S :BEGIN)) = 4.99E-4
;;; Finished <P: HB4.41A>
```



4.43 Water in the piston-cylinder device shown is initially 40 percent liquid and 60 percent vapor by mass and is at 0.2 MPa. A pressure of 0.4 MPa is required to raise the piston. The medium is heated to a final temperature of 250°C. Plot and label the process on a *T-v* diagram. Determine (*a*) the mass of the H_2O in the device and (*b*) the total work done in kilojoules.

```
(add-problem-description :hb4.43
 :givens '((piston (at can :begin))
           (dual-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (direction (at can :begin) :up)
           (piston-stop-for (at can :begin) (at stop :begin))
           (under (at stop :begin) (top (at can :begin)))
           (nvalue (P (at s :begin)) 0.2 Mpa)
           (substance-of (at s :begin) water)
           (nvalue (dryness (at s :begin)) 0.6)
           (circular-cylinder (at can :begin))
           (nvalue (radius (top (at can :begin))) 0.06 m)
           (nvalue (height (at can :begin)) 0.30 m)
           (heating htr (at s :begin) (at s :end))
           (nvalue (P (at s :end)) 0.4 Mpa)
           (nvalue (T (at S :end)) 250 C)))

(add-problem-goal :hb4.43a
  :description :hb4.43
  :goal '(find (nvalue (mass (at s :begin))))
  :answer '(0.006379 kg))

(add-problem-goal :hb4.43b
  :description :hb4.43
  :goal '(find (nvalue (work htr)))
  :answer '(0.1613 kJ))


;;; Answer-for :HB4.43A: 0.00637809854758905
;;; Answer is correct! Given (0.006379 KG) =~ 0.00637809854758905
```

```
;;; (NVALUE (MASS (AT S :BEGIN)) 0.00637809854758905)
Found (AREA (TOP (AT CAN :BEGIN))) = 0.0113097335529233
using equality
    (:= (AREA (TOP (AT CAN :BEGIN))) (* PI (RADIUS (TOP (AT CAN
:BEGIN))) (RADIUS (TOP (AT CAN :BEGIN)))))
Found (V (AT CAN :BEGIN)) = 0.00339292006587698
using
    V-OF-CYLINDER
    (:= (V (AT CAN :BEGIN)) (* (AREA (TOP (AT CAN :BEGIN))) (HEIGHT
(AT CAN :BEGIN))))
on
   (HEIGHT (AT CAN :BEGIN)) = 0.3
   (AREA (TOP (AT CAN :BEGIN))) = 0.0113097335529233
Found (V (AT S :BEGIN)) = 0.00339292006587698
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT S :BEGIN)))
Found (SPEC-VF (AT S :BEGIN)) = 0.00106049
using
    SATURATED-TABLE-P
on
   (P (AT S :BEGIN)) = 200000.0
Found (SPEC-VG (AT S :BEGIN)) = 0.8859
using
    SATURATED-TABLE-P
on
   (P (AT S :BEGIN)) = 200000.0
Found (SPEC-V (AT S :BEGIN)) = 0.531964196
using
    V-SATURATED-STUFF
    (:= (SPEC-V (AT S :BEGIN)) (+ (SPEC-VF (AT S :BEGIN)) (* (DRYNESS
(AT S :BEGIN)) (- (SPEC-VG (AT S :BEGIN)) (SPEC-VF (AT S :BEGIN))))))
on
   (DRYNESS (AT S :BEGIN)) = 0.6
   (SPEC-VG (AT S :BEGIN)) = 0.8859
   (SPEC-VF (AT S :BEGIN)) = 0.00106049
Found (DENSITY (AT S :BEGIN)) = 1.87982576180747
using equality
    (:= (DENSITY (AT S :BEGIN)) (/ 1 (SPEC-V (AT S :BEGIN))))
Found (MASS (AT S :BEGIN)) = 0.00637809854758905
using
    DENSITY-DEFINITION
    (:= (DENSITY (AT S :BEGIN)) (/ (MASS (AT S :BEGIN)) (V (AT S
:BEGIN))))
on
   (DENSITY (AT S :BEGIN)) = 1.87982576180747
   (V (AT S :BEGIN)) = 0.00339292006587698
;;; Finished <P: HB4.43A>
```



4.45 A frictionless piston-cylinder device containing H_20 is shown. The initial conditions are P_1 = 80 kPa and T_1 = 90°C. A pressure of 101.3 kPa is required to move the piston. If the H_2O is heated to a final temperature of 300°C, calculate the heat transfer and work (in kilojoules per kilogram).

```
(add-problem-description :hb4.45
 :givens '((piston (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (direction (at can :begin) :up)
           (piston-stop-for (at can :begin) (at stop :begin))
           (under (at stop :begin) (top (at can :begin)))
           (substance-of (at s :begin) water)
           (nvalue (P (at s :begin)) 80 kPa)
           (nvalue (T (at s :begin)) 90 C)
           (heating htr (at s :begin) (at s :end))
           (nvalue (T (at s :end)) 300 C)
           (nvalue (P (at s :end)) 101.3 kPa)))

(add-problem-goal :hb4.45a
  :description :hb4.45
  :goal '(find (nvalue (spec-q htr)))
  :answer '(2697 kJ/kg))

(add-problem-goal :hb4.45b
  :description :hb4.45
  :goal '(find (nvalue (spec-work htr)))
  :answer '(263.7 kJ/kg))

;;; Answer-for :HB4.45A: 2671437.36831052
;;; Answer is correct! Given (2697 KJ/KG) =~ 2671.43736831052
;;; (NVALUE (SPEC-Q HTR) 2671437.36831052)
Found (SPEC-U (AT S :BEGIN)) = 376192.742671985
using
    SUBCOOLED-P-T
on
   (P (AT S :BEGIN)) = 80000
```

```
   (T (AT S :BEGIN)) = 363.15
Found (SPEC-V (AT S :BEGIN)) = 0.00103465027557186
using
    SUBCOOLED-T-SPEC-U
on
   (T (AT S :BEGIN)) = 363.15
   (SPEC-U (AT S :BEGIN)) = 376192.742671985
Found (SPEC-U (AT S :END)) = 2810075.3
using
    SUPERHEATED-P-T
on
   (T (AT S :END)) = 573.15
   (P (AT S :END)) = 101300.0
Found (SPEC-V (AT S :END)) = 2.62160619999987
using
    SUPERHEATED-T-SPEC-U
on
   (T (AT S :END)) = 573.15
   (SPEC-U (AT S :END)) = 2810075.3
Found (SPEC-WORK HTR) = 237554.810982508
using
    SPEC-WORK=PDV-LINEAR
    (:= (SPEC-WORK HTR) (* (* (+ (P (AT S :BEGIN)) (P (AT S :END)))
0.5) (- (SPEC-V (AT S :END)) (SPEC-V (AT S :BEGIN)))))
on
   (P (AT S :BEGIN)) = 80000
   (P (AT S :END)) = 101300.0
   (SPEC-V (AT S :END)) = 2.62160619999987
   (SPEC-V (AT S :BEGIN)) = 0.00103465027557186
Found (SPEC-ENERGY (AT S :END)) = 2810075.3
using equality
    (:= (SPEC-ENERGY (AT S :END)) (SPEC-U (AT S :END)))
Found (SPEC-ENERGY-END HTR) = 2810075.3
using equality
    (:= (SPEC-ENERGY-END HTR) (SPEC-ENERGY (AT S :END)))
Found (SPEC-ENERGY (AT S :BEGIN)) = 376192.742671985
using equality
    (:= (SPEC-ENERGY (AT S :BEGIN)) (SPEC-U (AT S :BEGIN)))
Found (SPEC-ENERGY-BEGIN HTR) = 376192.742671985
using equality
    (:= (SPEC-ENERGY-BEGIN HTR) (SPEC-ENERGY (AT S :BEGIN)))
Found (SPEC-Q HTR) = 2671437.36831052
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q HTR) (SPEC-ENERGY-BEGIN HTR) (SPEC-ENERGY-INLET
HTR)) (+ (SPEC-ENERGY-END HTR) (SPEC-ENERGY-OUTLET HTR) (SPEC-WORK
HTR)))
on
   (SPEC-ENERGY-OUTLET HTR) = 0
   (SPEC-ENERGY-INLET HTR) = 0
   (SPEC-ENERGY-BEGIN HTR) = 376192.742671985
   (SPEC-ENERGY-END HTR) = 2810075.3
   (SPEC-WORK HTR) = 237554.810982508
;;; Finished <P: HB4.45A>
```

```
;;; Answer-for :HB4.45B: 237554.594168299
;;; Answer is correct! Given (263.7 KJ/KG) =~ 237.554594168299
;;; (NVALUE (SPEC-WORK HTR) 237554.594168299)
Found (SPEC-V (AT S :BEGIN)) = 0.00103704204855044
using
    SUBCOOLED-P-T
on
   (P (AT S :BEGIN)) = 80000
   (T (AT S :BEGIN)) = 363.15
Found (SPEC-V (AT S :END)) = 2.6216062
using
    SUPERHEATED-P-T
on
   (T (AT S :END)) = 573.15
   (P (AT S :END)) = 101300.0
Found (SPEC-WORK HTR) = 237554.594168299
using
    SPEC-WORK=PDV-LINEAR
    (:= (SPEC-WORK HTR) (* (* (+ (P (AT S :BEGIN)) (P (AT S :END)))
0.5) (- (SPEC-V (AT S :END)) (SPEC-V (AT S :BEGIN)))))
on
   (P (AT S :BEGIN)) = 80000
   (P (AT S :END)) = 101300.0
   (SPEC-V (AT S :END)) = 2.6216062
   (SPEC-V (AT S :BEGIN)) = 0.00103704204855044
;;; Finished <P: HB4.45B>
```

4.47 A frictionless piston-cylinder device containing H_2O is shown. The initial conditions are P = 400 kPa and T= 800°C. A pressure of 0.1 MPa is required to support the piston. There is a heat transfer from the device until T = 80°C. Draw and label the process on a T-v plot, and calculate the heat transfer and work (kJ/kg) transferred.

```
(add-problem-description :hb4.47
 :givens '((piston (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (direction (at can :begin) :up)
           (piston-stop-for (at can :begin) (at stop :begin))
           (under (at stop :begin) (top (at can :begin)))
           (substance-of (at s :begin) water)
           (nvalue (P (at s :begin)) 400 kPa)
           (nvalue (T (at s :begin)) 800 C)
           (cooling cool (at s :begin) (at s :end))
           (nvalue (T (at s :end)) 80 C)
           (nvalue (P (at s :end)) 0.1 MPa)))

(add-problem-goal :hb4.47a
  :description :hb4.47
  :goal '(find (nvalue (spec-q cool)))
  :answer '(-3451 kJ/kg))

(add-problem-goal :hb4.47b
```

```
  :description :hb4.47
  :goal '(find (nvalue (spec-work cool)))
  :answer '(-123.6 kJ/kg))

;;; Answer-for :HB4.47A: -3637607.75
;;; Answer is correct! Given (-3451 KJ/KG) =~ -3637.60775
;;; (NVALUE (SPEC-Q COOL) -3637607.75)
Found (SPEC-U (AT S :BEGIN)) = 3663400.0
using
    SUPERHEATED-P-T
on
   (P (AT S :BEGIN)) = 400000
   (T (AT S :BEGIN)) = 1073.15
Found (SPEC-V (AT S :BEGIN)) = 1.2373
using
    SUPERHEATED-T-SPEC-U
on
   (T (AT S :BEGIN)) = 1073.15
   (SPEC-U (AT S :BEGIN)) = 3663400.0
Found (SPEC-U (AT S :END)) = 334860.0
using
    SUBCOOLED-P-T
on
   (T (AT S :END)) = 353.15
   (P (AT S :END)) = 100000.0
Found (SPEC-V (AT S :END)) = 0.001029
using
    SUBCOOLED-T-SPEC-U
on
   (T (AT S :END)) = 353.15
   (SPEC-U (AT S :END)) = 334860.0
Found (SPEC-WORK COOL) = -309067.75
using
    SPEC-WORK=PDV-LINEAR
    (:= (SPEC-WORK COOL) (* (* (+ (P (AT S :BEGIN)) (P (AT S :END)))
0.5) (- (SPEC-V (AT S :END)) (SPEC-V (AT S :BEGIN)))))
on
   (P (AT S :BEGIN)) = 400000
   (P (AT S :END)) = 100000.0
   (SPEC-V (AT S :END)) = 0.001029
   (SPEC-V (AT S :BEGIN)) = 1.2373
Found (SPEC-ENERGY (AT S :END)) = 334860.0
using equality
    (:= (SPEC-ENERGY (AT S :END)) (SPEC-U (AT S :END)))
Found (SPEC-ENERGY-END COOL) = 334860.0
using equality
    (:= (SPEC-ENERGY-END COOL) (SPEC-ENERGY (AT S :END)))
Found (SPEC-ENERGY (AT S :BEGIN)) = 3663400.0
using equality
    (:= (SPEC-ENERGY (AT S :BEGIN)) (SPEC-U (AT S :BEGIN)))
Found (SPEC-ENERGY-BEGIN COOL) = 3663400.0
using equality
    (:= (SPEC-ENERGY-BEGIN COOL) (SPEC-ENERGY (AT S :BEGIN)))
Found (SPEC-Q COOL) = -3637607.75
using
    SPEC-CONSERVATION-OF-ENERGY
```

```
    (:= (+ (SPEC-Q COOL) (SPEC-ENERGY-BEGIN COOL) (SPEC-ENERGY-INLET
COOL)) (+ (SPEC-ENERGY-END COOL) (SPEC-ENERGY-OUTLET COOL) (SPEC-WORK
COOL)))
on
   (SPEC-ENERGY-OUTLET COOL) = 0
   (SPEC-ENERGY-INLET COOL) = 0
   (SPEC-ENERGY-BEGIN COOL) = 3663400.0
   (SPEC-ENERGY-END COOL) = 334860.0
   (SPEC-WORK COOL) = -309067.75
;;; Finished <P: HB4.47A>


;;; Answer-for :HB4.47B: -309067.75
;;; (NVALUE (SPEC-WORK COOL) -309067.75)
Found (SPEC-V (AT S :BEGIN)) = 1.2373
using
    SUPERHEATED-P-T
on
   (P (AT S :BEGIN)) = 400000
   (T (AT S :BEGIN)) = 1073.15
Found (SPEC-V (AT S :END)) = 0.001029
using
    SUBCOOLED-P-T
on
   (T (AT S :END)) = 353.15
   (P (AT S :END)) = 100000.0
Found (SPEC-WORK COOL) = -309067.75
using
    SPEC-WORK=PDV-LINEAR
    (:= (SPEC-WORK COOL) (* (* (+ (P (AT S :BEGIN)) (P (AT S :END)))
0.5) (- (SPEC-V (AT S :END)) (SPEC-V (AT S :BEGIN)))))
on
   (P (AT S :BEGIN)) = 400000
   (P (AT S :END)) = 100000.0
   (SPEC-V (AT S :END)) = 0.001029
   (SPEC-V (AT S :BEGIN)) = 1.2373
;;; Finished <P: HB4.47B>
```

4.57S Water in a rigid vessel initially at the critical point is cooled until the pressure is 20 MPa. Determine the work and heat transfer (kJ/kg) for the process.

```
(add-problem-description :hb4.57
 :givens '((container (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (rigid (at can :begin))
           (substance-of (at s :begin) water)
           (= (P (at s :begin)) (P-critical water))
           (= (T (at s :begin)) (T-critical water))
           (cooling cool (at s :begin) (at s :end))
           (nvalue (P (at s :end)) 20 MPa)))


(add-problem-goal :hb4.57a
  :description :hb4.57
```

```
  :goal '(find (nvalue (work cool)))
  :answer '(0))

(add-problem-goal :hb4.57b
  :description :hb4.57
  :goal '(find (nvalue (spec-q cool)))
  :answer '(-88.3 kj/kg))

;;; Answer-for :HB4.57A: 0
;;; Answer is correct! Given (0) =~ 0
;;; (NVALUE (WORK COOL) 0)
;;; There is no work in rigid containers
;;; Finished <P: HB4.57A>
```

4.65 Air in a nonflow device is heated isobarically from 10°C and 200 kPa to 400°C. Determine the work (kJ/kg) and heat transferred (kJ/kg).

```
(add-problem :hb4.65
 :givens '((container (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (substance-of (at s :begin) air)
           (nvalue (P (at s :begin)) 200 kPa)
           (nvalue (T (at s :begin)) 10 C)
           (heating htr (at s :begin) (at s :end))
           (isobaric htr)
           (nvalue (T (at s :end)) 400 C))
 :goal '(find (nvalue (spec-work htr)))
 :answer '(111.93 kJ/kg))


;;; Answer-for :HB4.65: 111930.0
;;; Answer is correct! Given (111.93 KJ/KG) =~ 111.93
;;; (NVALUE (SPEC-WORK HTR) 111930.0)
Found (P (AT S :END)) = 200000
using equality
    (:= (P (AT S :BEGIN)) (P (AT S :END)))
Found (SPEC-V (AT S :END)) = 0.96597025
using
    IDEAL-GAS-SPEC-VOLUME
    (:= (* (P (AT S :END)) (SPEC-V (AT S :END))) (* (R AIR) (T (AT S
:END))))
on
   (P (AT S :END)) = 200000
   (T (AT S :END)) = 673.15
   (R AIR) = 287
Found (SPEC-V (AT S :BEGIN)) = 0.40632025
using
    PSPEC-V/T=P2SPEC-V2/T2
    (:= (/ (* (P (AT S :BEGIN)) (SPEC-V (AT S :BEGIN))) (T (AT S
:BEGIN))) (/ (* (P (AT S :END)) (SPEC-V (AT S :END))) (T (AT S
:END))))
on
   (P (AT S :BEGIN)) = 200000
```

```
   (T (AT S :BEGIN)) = 283.15
   (P (AT S :END)) = 200000
   (T (AT S :END)) = 673.15
   (SPEC-V (AT S :END)) = 0.96597025
Found (SPEC-WORK HTR) = 111930.0
using
    SPEC-WORK=PDV-ISOBARIC
    (:= (SPEC-WORK HTR) (* (P (AT S :BEGIN)) (- (SPEC-V (AT S :END))
(SPEC-V (AT S :BEGIN)))))
on
   (P (AT S :BEGIN)) = 200000
   (SPEC-V (AT S :END)) = 0.96597025
   (SPEC-V (AT S :BEGIN)) = 0.40632025
;;; Finished <P: HB4.65>
```

4.69 Oxygen (0.1 kg) is contained in a cylinder fitted with a piston. The initial conditions are 150 kPa and 20°C. Weights are then added to the piston, and the O_2 is slowly compressed isothermally until the final pressure is 500 kPa. Determine the change in internal energy (kJ/kg) and the final volume (m^3).

```
(add-problem-description :hb4.69
 :givens '((piston (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (direction (at can :begin) :up)
           (substance-of (at s :begin) oxygen)
           (nvalue (mass (at s :begin)) 0.1 kg)
           (nvalue (P (at s :begin)) 150 kPa)
           (nvalue (T (at s :begin)) 20 C)
           (compressing cmp (at s :begin) (at s :end))
           (isothermal cmp)
           (nvalue (P (at s :end)) 500 kPa)))

(add-problem-goal :hb4.69a
  :description :hb4.69
  :extras '((given-equation u-difference
              (:= (delta-U cmp)
               (- (U (at s :end)) (U (at s :begin))))))
 :goal '(find (nvalue (delta-U cmp)))
 :answer '(0))

(add-problem-goal :hb4.69b
  :description :hb4.69
 :goal '(find (nvalue (V (at s :end))))
 :answer '(0.0152 m^3))


;;; Answer-for :HB4.69A: 0.0
;;; Answer is correct! Given (0) =~ 0.0
;;; (NVALUE (DELTA-U CMP) 0.0)
Found (SPEC-U (AT S :BEGIN)) = 193185.85
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :BEGIN)) (* (CV OXYGEN) (T (AT S :BEGIN))))
```

```
on
   (T (AT S :BEGIN)) = 293.15
   (CV OXYGEN) = 659.0
Found (U (AT S :BEGIN)) = 19318.585
using
    SPEC-U-DEFINITION
    (:= (SPEC-U (AT S :BEGIN)) (/ (U (AT S :BEGIN)) (MASS (AT S
:BEGIN))))
on
   (MASS (AT S :BEGIN)) = 0.1
   (SPEC-U (AT S :BEGIN)) = 193185.85
Found (MASS-BEGIN CMP) = 0.1
using equality
    (:= (MASS-BEGIN CMP) (MASS (AT S :BEGIN)))
Found (MASS-END CMP) = 0.1
using
    CONSERVATION-OF-MASS
    (:= (+ (MASS-BEGIN CMP) (MASS-INLET CMP)) (+ (MASS-END CMP)
(MASS-OUTLET CMP)))
on
   (MASS-BEGIN CMP) = 0.1
   (MASS-OUTLET CMP) = 0
   (MASS-INLET CMP) = 0
Found (MASS (AT S :END)) = 0.1
using equality
    (:= (MASS-END CMP) (MASS (AT S :END)))
Found (T (AT S :END)) = 293.15
using equality
    (:= (T (AT S :BEGIN)) (T (AT S :END)))
Found (SPEC-U (AT S :END)) = 193185.85
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :END)) (* (CV OXYGEN) (T (AT S :END))))
on
   (T (AT S :END)) = 293.15
   (CV OXYGEN) = 659.0
Found (U (AT S :END)) = 19318.585
using
    SPEC-U-DEFINITION
    (:= (SPEC-U (AT S :END)) (/ (U (AT S :END)) (MASS (AT S :END))))
on
   (SPEC-U (AT S :END)) = 193185.85
   (MASS (AT S :END)) = 0.1
Found (DELTA-U CMP) = 0.0
using
    U-DIFFERENCE
    (:= (DELTA-U CMP) (- (U (AT S :END)) (U (AT S :BEGIN))))
on
   (U (AT S :END)) = 19318.585
   (U (AT S :BEGIN)) = 19318.585
;;; Finished <P: HB4.69A>


;;; Answer-for :HB4.69B: 0.0152438
;;; Answer is correct! Given (0.0152 M^3) =~ 0.0152438
;;; (NVALUE (V (AT S :END)) 0.0152438)
```

```
Found (R OXYGEN) = 260.0
using
    CP-CV-R-RELATION
    (:= (CP OXYGEN) (+ (CV OXYGEN) (R OXYGEN)))
on
   (CV OXYGEN) = 659.0
   (CP OXYGEN) = 919.0
Found (V (AT S :BEGIN)) = 0.0508126666666667
using
    IDEAL-GAS-LAW
    (:= (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (* (MASS (AT S
:BEGIN)) (R OXYGEN) (T (AT S :BEGIN))))
on
   (MASS (AT S :BEGIN)) = 0.1
   (P (AT S :BEGIN)) = 150000
   (T (AT S :BEGIN)) = 293.15
   (R OXYGEN) = 260.0
Found (T (AT S :END)) = 293.15
using equality
    (:= (T (AT S :BEGIN)) (T (AT S :END)))
Found (V (AT S :END)) = 0.0152438
using
    PV/T=P2V2/T2
    (:= (/ (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (T (AT S :BEGIN)))
(/ (* (P (AT S :END)) (V (AT S :END))) (T (AT S :END))))
on
   (P (AT S :BEGIN)) = 150000
   (T (AT S :BEGIN)) = 293.15
   (T (AT S :END)) = 293.15
   (P (AT S :END)) = 500000
   (V (AT S :BEGIN)) = 0.0508126666666667
;;; Finished <P: HB4.69B>
```

4.71 One kilogram of air in a closed, rigid container under goes a process such that its temperature increases from 10 to 50°C. The volume of the container is 25,000 cm^3. Find the amount of work done during the process.

```
(add-problem :hb4.71
 :givens '((container (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (rigid (at can :begin))
           (closed (at can :begin))
           (substance-of (at s :begin) AIR)
           (nvalue (T (at s :begin)) 10 C)
           (nvalue (V (at can :begin)) 25000 cm^3)
           (contained-process mystery (at s :begin) (at s :end))
           (nvalue (T (at s :end)) 50 C))
 :goal '(find (nvalue (work mystery)))
 :answer '(0))

;;; Answer-for :HB4.71: 0
;;; Answer is correct! Given (0) =~ 0
```

```
;;; (NVALUE (WORK MYSTERY) 0)
;;; There is no work in rigid containers
;;; Finished <P: HB4.71>
```

4.73 Oxygen in a system undergoes the process shown on the *P-v* diagram. Find the work done. Is it work done on or by the system?

```
(add-problem :hb4.73
 :givens '((static-thermodynamic-stuff (at S :begin))
           (substance-of (at s :begin) oxygen)
           (process cmp (at s :begin) (at s :end))
           (given-graph P-v-4.73))
 :goal '(find (nvalue (spec-work cmp)))
 :answer '(175 kJ/kg))
```

4.79 Air is cooled in a closed rigid vessel from a temperature of 600°C and pressure of 4.0 MPa to a temperature of l00°C.

(*a*) How much work is done?

(b) What is the final pressure?

```
(add-problem-description :hb4.79
 :givens '((container (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (rigid (at can :begin))
           (closed (at can :begin))
           (substance-of (at s :begin) air)
           (nvalue (P (at s :begin)) 4.0 MPa)
           (nvalue (T (at s :begin)) 600 C)
           (cooling cool (at s :begin) (at s :end))
           (nvalue (T (at s :end)) 100 C)))

(add-problem-goal :hb4.79a
  :description :hb4.79
  :goal '(find (nvalue (work cool)))
  :answer '(0))

(add-problem-goal :hb4.79b
  :description :hb4.79
  :extras '((given-equation constant-spec-v
              (:= (spec-v (at s :end)) (spec-v (at s :begin)))))
  :goal '(find (nvalue (P (at s :end))))
  :answer '(1.709 MPa))


;;; Answer-for :HB4.79B: 1709442.82196644
;;; Answer is correct! Given (1.709 MPA) =~ 1.70944282196644
;;; (NVALUE (P (AT S :END)) 1709442.82196644)
Found (SPEC-V (AT S :BEGIN)) = 0.0626485125
using
```

```
    IDEAL-GAS-SPEC-VOLUME
    (:= (* (P (AT S :BEGIN)) (SPEC-V (AT S :BEGIN))) (* (R AIR) (T
(AT S :BEGIN))))
on
   (P (AT S :BEGIN)) = 4000000.0
   (T (AT S :BEGIN)) = 873.15
   (R AIR) = 287
Found (SPEC-V (AT S :END)) = 0.0626485125
using equality
    (:= (SPEC-V (AT S :END)) (SPEC-V (AT S :BEGIN)))
Found (P (AT S :END)) = 1709442.82196644
using
    PSPEC-V/T=P2SPEC-V2/T2
    (:= (/ (* (P (AT S :BEGIN)) (SPEC-V (AT S :BEGIN))) (T (AT S
:BEGIN))) (/ (* (P (AT S :END)) (SPEC-V (AT S :END))) (T (AT S
:END))))
on
   (P (AT S :BEGIN)) = 4000000.0
   (T (AT S :BEGIN)) = 873.15
   (T (AT S :END)) = 373.15
   (SPEC-V (AT S :BEGIN)) = 0.0626485125
   (SPEC-V (AT S :END)) = 0.0626485125
;;; Finished <P: HB4.79B>
```

4.81 Oxygen is contained in a piston-cylinder device, and the piston is free to move. Initially the oxygen is at a pressure of 0.6 MPa and a temperature of 188.9°C. The oxygen is cooled until the specific volume is 0.15 m^3/kg. Determine the work done on the system (kJ/kg) and the mass of the oxygen, if the total work done on the system is 30 kJ.

```
(add-problem-description :hb4.81
 :givens '((piston (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (direction (at can :begin) :up)
           (substance-of (at s :begin) oxygen)
           (nvalue (P (at s :begin)) 0.6 MPa)
           (nvalue (T (at s :begin)) 188.9 C)
           (cooling cool (at s :begin) (at s :end))
           (nvalue (spec-v (at s :end)) 0.15 m^3/kg)))

(add-problem-goal :hb4.81a
  :description :hb4.81
  :goal '(find (nvalue (spec-work cool)))
  :answer '(-30 kj/kg))

(add-problem-goal :hb4.81b
  :description :hb4.81
  :extras '((nvalue (work cool) -30 kJ))
  :goal '(find (nvalue (mass (at s :begin))))
  :answer '(1 kg))

;;; Answer-for :HB4.81A: -30133.0
```

```
;;; Answer is correct! Given (-30 KJ/KG) =~ -30.133
;;; (NVALUE (SPEC-WORK COOL) -30133.0)
Found (R OXYGEN) = 260.0
using
    CP-CV-R-RELATION
    (:= (CP OXYGEN) (+ (CV OXYGEN) (R OXYGEN)))
on
   (CV OXYGEN) = 659.0
   (CP OXYGEN) = 919.0
Found (SPEC-V (AT S :BEGIN)) = 0.200221666666667
using
    IDEAL-GAS-SPEC-VOLUME
    (:= (* (P (AT S :BEGIN)) (SPEC-V (AT S :BEGIN))) (* (R OXYGEN) (T
(AT S :BEGIN))))
on
   (P (AT S :BEGIN)) = 600000.0
   (T (AT S :BEGIN)) = 462.05
   (R OXYGEN) = 260.0
Found (SPEC-WORK COOL) = -30133.0
using
    SPEC-WORK=PDV-ISOBARIC
    (:= (SPEC-WORK COOL) (* (P (AT S :BEGIN)) (- (SPEC-V (AT S :END))
(SPEC-V (AT S :BEGIN)))))
on
   (P (AT S :BEGIN)) = 600000.0
   (SPEC-V (AT S :END)) = 0.15
   (SPEC-V (AT S :BEGIN)) = 0.200221666666667
```

;;; Finished <P: HB4.81A>

```
;;; Answer-for :HB4.81B: 0.995586234361
;;; Answer is correct! Given (1 KG) =~ 0.995586234361
;;; (NVALUE (MASS (AT S :BEGIN)) 0.995586234361)
Found (R OXYGEN) = 260.0
using
    CP-CV-R-RELATION
    (:= (CP OXYGEN) (+ (CV OXYGEN) (R OXYGEN)))
on
   (CV OXYGEN) = 659.0
   (CP OXYGEN) = 919.0
Found (SPEC-V (AT S :BEGIN)) = 0.200221666666667
using
    IDEAL-GAS-SPEC-VOLUME
    (:= (* (P (AT S :BEGIN)) (SPEC-V (AT S :BEGIN))) (* (R OXYGEN) (T
(AT S :BEGIN))))
on
   (P (AT S :BEGIN)) = 600000.0
   (T (AT S :BEGIN)) = 462.05
   (R OXYGEN) = 260.0
Found (SPEC-WORK COOL) = -30133.0
using
    SPEC-WORK=PDV-ISOBARIC
    (:= (SPEC-WORK COOL) (* (P (AT S :BEGIN)) (- (SPEC-V (AT S :END))
(SPEC-V (AT S :BEGIN)))))
on
   (P (AT S :BEGIN)) = 600000.0
   (SPEC-V (AT S :END)) = 0.15
```

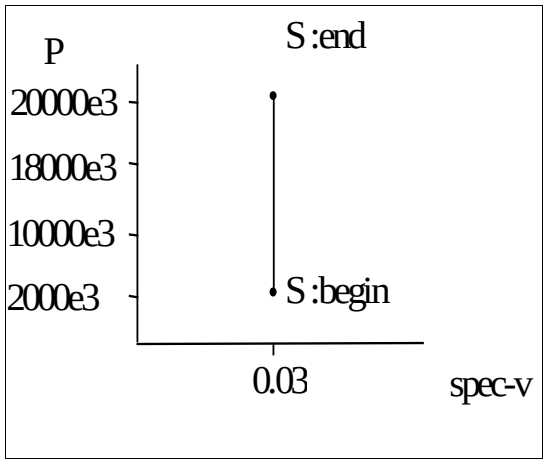
```
   (SPEC-V (AT S :BEGIN)) = 0.200221666666667
Found (MASS-BEGIN COOL) = 0.995586234361
using
    WORK-DEFINITION
    (:= (WORK COOL) (* (SPEC-WORK COOL) (MASS-BEGIN COOL)))
on
   (WORK COOL) = -30000
   (SPEC-WORK COOL) = -30133.0
Found (MASS (AT S :BEGIN)) = 0.995586234361
using equality
    (:= (MASS-BEGIN COOL) (MASS (AT S :BEGIN)))
```
;;; Finished <P: HB4.81B>

4.83 A rigid aluminum container with a volume of 0.755 m^3 contains 25 kg of carbon dioxide at an initial pressure of 2.0 MPa. If the manufacturer's specifications state that the container will rupture at 20.09 MPa Pressure, what is the total heat transfer required to rupture the container? Show the process on a *P-v* diagram.

```
(add-problem-description :hb4.83
 :givens '((container (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (closed (at can :begin))
           (rigid (at can :begin))
           (nvalue (V (at can :begin)) 0.755 m^3)
           (nvalue (mass (at S :begin)) 25 kg)
           (nvalue (P (at S :begin)) 2.0 MPa)
           (substance-of (at s :begin) co2)
           (heating htr (at s :begin) (at s :end))
           (nvalue (P (at s :end)) 20.09 Mpa)))

(add-problem-goal :hb4.83a
  :description :hb4.83
  :goal '(find (nvalue (q htr)))
  :answer '(47288 kJ))

(add-problem-goal :hb4.83b
  :description :hb4.83
  :goal '(plot-graph (P spec-v) htr))

;;; Answer-for :HB4.83A: 4.72013315424518E7
;;; Answer is correct! Given (47288 KJ) =~ 47201.3315424518
;;; (NVALUE (Q HTR) 4.72013315424518E7)
Found (V (AT S :BEGIN)) = 0.755
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT S :BEGIN)))
Found (T (AT S :BEGIN)) = 319.712047427483
using
    IDEAL-GAS-LAW
    (:= (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (* (MASS (AT S
:BEGIN)) (R CO2) (T (AT S :BEGIN))))
on
   (V (AT S :BEGIN)) = 0.755
```

```
   (MASS (AT S :BEGIN)) = 25
   (P (AT S :BEGIN)) = 2000000.0
   (R CO2) = 188.92
Found (V (AT CAN :END)) = 0.755
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT CAN :END)))
Found (V (AT S :END)) = 0.755
using equality
    (:= (V (AT CAN :END)) (V (AT S :END)))
Found (T (AT S :END)) = 3211.50751640906
using
    PV/T=P2V2/T2
    (:= (/ (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (T (AT S :BEGIN)))
(/ (* (P (AT S :END)) (V (AT S :END))) (T (AT S :END))))
on
   (V (AT S :BEGIN)) = 0.755
   (P (AT S :BEGIN)) = 2000000.0
   (P (AT S :END)) = 2.009E7
   (V (AT S :END)) = 0.755
   (T (AT S :BEGIN)) = 319.712047427483
Found (MASS (AT S :END)) = 25.0
using
    IDEAL-GAS-LAW
    (:= (* (P (AT S :END)) (V (AT S :END))) (* (MASS (AT S :END)) (R
CO2) (T (AT S :END))))
on
   (P (AT S :END)) = 2.009E7
   (V (AT S :END)) = 0.755
   (R CO2) = 188.92
   (T (AT S :END)) = 3211.50751640906
Found (SPEC-U (AT S :END)) = 2096793.25746348
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :END)) (* (CV CO2) (T (AT S :END))))
on
   (CV CO2) = 652.9
   (T (AT S :END)) = 3211.50751640906
Found (U (AT S :END)) = 5.24198314365869E7
using
    SPEC-U-DEFINITION
    (:= (SPEC-U (AT S :END)) (/ (U (AT S :END)) (MASS (AT S :END))))
on
   (SPEC-U (AT S :END)) = 2096793.25746348
   (MASS (AT S :END)) = 25.0
Found (ENERGY (AT S :END)) = 5.24198314365869E7
using equality
    (:= (ENERGY (AT S :END)) (U (AT S :END)))
Found (ENERGY-END HTR) = 5.24198314365869E7
using equality
    (:= (ENERGY-END HTR) (ENERGY (AT S :END)))
Found (SPEC-U (AT S :BEGIN)) = 208739.995765403
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :BEGIN)) (* (CV CO2) (T (AT S :BEGIN))))
on
   (CV CO2) = 652.9
```

```
   (T (AT S :BEGIN)) = 319.712047427483
Found (U (AT S :BEGIN)) = 5218499.89413508
using
    SPEC-U-DEFINITION
    (:= (SPEC-U (AT S :BEGIN)) (/ (U (AT S :BEGIN)) (MASS (AT S
:BEGIN))))
on
   (MASS (AT S :BEGIN)) = 25
   (SPEC-U (AT S :BEGIN)) = 208739.995765403
Found (ENERGY (AT S :BEGIN)) = 5218499.89413508
using equality
    (:= (ENERGY (AT S :BEGIN)) (U (AT S :BEGIN)))
Found (ENERGY-BEGIN HTR) = 5218499.89413508
using equality
    (:= (ENERGY-BEGIN HTR) (ENERGY (AT S :BEGIN)))
Found (Q HTR) = 4.72013315424518E7
using
    CONSERVATION-OF-ENERGY
    (:= (+ (Q HTR) (ENERGY-BEGIN HTR) (ENERGY-INLET HTR)) (+ (ENERGY-
END HTR) (ENERGY-OUTLET HTR) (WORK HTR)))
on
   (WORK HTR) = 0
   (ENERGY-OUTLET HTR) = 0
   (ENERGY-INLET HTR) = 0
   (ENERGY-BEGIN HTR) = 5218499.89413508
   (ENERGY-END HTR) = 5.24198314365869E7
;;; Finished <P: HB4.83A>
```



4.89 A sealed rigid container has a volume of 8.03 x 10^{-2} m^3. It contains carbon monoxide at an initial temperature and pressure of 500°C and 20 MPa. It is then cooled to 200°C. Determine (*a*) the mass of the carbon monoxide, (*b*) the work done during the process, and (*c*) the total heat transfer.

```
(add-problem-description :hb4.89
 :givens '((container (at can :begin))
```

```
            (static-thermodynamic-stuff (at S :begin))
            (inside (at S :begin) (at can :begin))
            (rigid (at can :begin))
            (nvalue (V (at can :begin)) 0.0803 m^3)
            (substance-of (at s :begin) carbon-monoxide)
            (nvalue (P (at s :begin)) 20 MPa)
            (nvalue (T (at s :begin)) 500 C)
            (cooling cool (at s :begin) (at s :end))
            (nvalue (T (at s :end)) 200 C)))

(add-problem-goal :hb4.89a
  :description :hb4.89
 :goal '(find (nvalue (mass (at s :begin))))
 :answer '(7 kg))

(add-problem-goal :hb4.89b
  :description :hb4.89
  :goal '(find (nvalue (work cool)))
  :answer '(0))

(add-problem-goal :hb4.89c
  :description :hb4.89
  :goal '(find (nvalue (Q cool)))
  :answer '(-1563 kJ))


;;; Answer-for :HB4.89A: 6.99800081365485
;;; Answer is correct! Given (7 KG) =~ 6.99800081365485
;;; (NVALUE (MASS (AT S :BEGIN)) 6.99800081365485)
Found (V (AT S :BEGIN)) = 0.0803
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT S :BEGIN)))
Found (MASS (AT S :BEGIN)) = 6.99800081365485
using
    IDEAL-GAS-LAW
    (:= (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (* (MASS (AT S
:BEGIN)) (R CARBON-MONOXIDE) (T (AT S :BEGIN))))
on
   (P (AT S :BEGIN)) = 20000000
   (T (AT S :BEGIN)) = 773.15
   (V (AT S :BEGIN)) = 0.0803
   (R CARBON-MONOXIDE) = 296.83
;;; Finished <P: HB4.89A>


;;; Answer-for :HB4.89B: 0
;;; Answer is correct! Given (0) =~ 0
;;; (NVALUE (WORK COOL) 0)
;;; Finished <P: HB4.89B>
;;; Solving <P: HB4.89C>
;;; Aborted :HB4.89C with SOLVED
;;; Time spent: 13 seconds
;;; Answer-for :HB4.89C: -1562163.72163217
;;; Answer is correct! Given (-1563 KJ) =~ -1562.16372163217
;;; (NVALUE (Q COOL) -1562163.72163217)
Found (V (AT CAN :END)) = 0.0803
```

```
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT CAN :END)))
Found (V (AT S :END)) = 0.0803
using equality
    (:= (V (AT CAN :END)) (V (AT S :END)))
Found (V (AT S :BEGIN)) = 0.0803
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT S :BEGIN)))
Found (P (AT S :END)) = 1.22395395460131E7
using
    PV/T=P2V2/T2
    (:= (/ (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (T (AT S :BEGIN)))
(/ (* (P (AT S :END)) (V (AT S :END))) (T (AT S :END))))
on
   (P (AT S :BEGIN)) = 20000000
   (T (AT S :BEGIN)) = 773.15
   (T (AT S :END)) = 473.15
   (V (AT S :BEGIN)) = 0.0803
   (V (AT S :END)) = 0.0803
Found (MASS (AT S :END)) = 6.99800081365485
using
    IDEAL-GAS-LAW
    (:= (* (P (AT S :END)) (V (AT S :END))) (* (MASS (AT S :END)) (R
CARBON-MONOXIDE) (T (AT S :END))))
on
   (T (AT S :END)) = 473.15
   (V (AT S :END)) = 0.0803
   (R CARBON-MONOXIDE) = 296.83
   (P (AT S :END)) = 1.22395395460131E7
Found (SPEC-U (AT S :END)) = 352070.915
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :END)) (* (CV CARBON-MONOXIDE) (T (AT S
:END))))
on
   (T (AT S :END)) = 473.15
   (CV CARBON-MONOXIDE) = 744.1
Found (U (AT S :END)) = 2463792.54963421
using
    SPEC-U-DEFINITION
    (:= (SPEC-U (AT S :END)) (/ (U (AT S :END)) (MASS (AT S :END))))
on
   (SPEC-U (AT S :END)) = 352070.915
   (MASS (AT S :END)) = 6.99800081365485
Found (ENERGY (AT S :END)) = 2463792.54963421
using equality
    (:= (ENERGY (AT S :END)) (U (AT S :END)))
Found (ENERGY-END COOL) = 2463792.54963421
using equality
    (:= (ENERGY-END COOL) (ENERGY (AT S :END)))
Found (MASS (AT S :BEGIN)) = 6.99800081365485
using
    IDEAL-GAS-LAW
    (:= (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (* (MASS (AT S
:BEGIN)) (R CARBON-MONOXIDE) (T (AT S :BEGIN))))
on
```

```
   (P (AT S :BEGIN)) = 20000000
   (T (AT S :BEGIN)) = 773.15
   (V (AT S :BEGIN)) = 0.0803
   (R CARBON-MONOXIDE) = 296.83
Found (SPEC-U (AT S :BEGIN)) = 575300.915
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :BEGIN)) (* (CV CARBON-MONOXIDE) (T (AT S
:BEGIN))))
on
   (T (AT S :BEGIN)) = 773.15
   (CV CARBON-MONOXIDE) = 744.1
Found (U (AT S :BEGIN)) = 4025956.27126638
using
    SPEC-U-DEFINITION
    (:= (SPEC-U (AT S :BEGIN)) (/ (U (AT S :BEGIN)) (MASS (AT S
:BEGIN))))
on
   (SPEC-U (AT S :BEGIN)) = 575300.915
   (MASS (AT S :BEGIN)) = 6.99800081365485
Found (ENERGY (AT S :BEGIN)) = 4025956.27126638
using equality
    (:= (ENERGY (AT S :BEGIN)) (U (AT S :BEGIN)))
Found (ENERGY-BEGIN COOL) = 4025956.27126638
using equality
    (:= (ENERGY-BEGIN COOL) (ENERGY (AT S :BEGIN)))
Found (Q COOL) = -1562163.72163217
using
    CONSERVATION-OF-ENERGY
    (:= (+ (Q COOL) (ENERGY-BEGIN COOL) (ENERGY-INLET COOL)) (+
(ENERGY-END COOL) (ENERGY-OUTLET COOL) (WORK COOL)))
on
   (WORK COOL) = 0
   (ENERGY-OUTLET COOL) = 0
   (ENERGY-INLET COOL) = 0
   (ENERGY-BEGIN COOL) = 4025956.27126638
   (ENERGY-END COOL) = 2463792.54963421
;;; Finished <P: HB4.89C>
```

4.91 A rigid spherical container has a volume of 1 m^3. It is filled with 46.14 g of hydrogen initially at 260°C. The medium is heated to a temperature of 300°C. Plot the process on a *P-v* diagram and determine (*a*) the work done (kJ/kg) and (*b*) the change in pressure (kPa).

```
(add-problem-description :hb4.91
 :givens '((container (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (sphere (at can :begin))
           (rigid (at can :begin))
           (nvalue (V (at can :begin)) 1 m^3)
           (nvalue (mass (at s :begin)) 46.14 g)
           (substance-of (at s :begin) hydrogen)
           (nvalue (T (at s :begin)) 260 C)
```

```
            (heating htr (at s :begin) (at s :end))
            (nvalue (T (at s :end)) 300 C)))

(add-problem-goal :hb4.91a
  :description :hb4.91
  :goal '(find (nvalue (spec-work htr)))
  :answer '(0 kJ/kg))

(add-problem-goal :hb4.91b
  :description :hb4.91
  :goal '(find (nvalue (delta-P htr)))
  :answer '(7.6 kPa))

;;; Answer-for :HB4.91A: 0
;;; Answer is correct! Given (0 KJ/KG) =~ 0
;;; (NVALUE (SPEC-WORK HTR) 0)
;;; Finished <P: HB4.91A>


;;; Answer-for :HB4.91B: 7611.586608
;;; Answer is correct! Given (7.6 KPA) =~ 7.611586608
;;; (NVALUE (DELTA-P HTR) 7611.586608)
Found (V (AT S :BEGIN)) = 1
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT S :BEGIN)))
Found (P (AT S :BEGIN)) = 101452.93500138
using
    IDEAL-GAS-LAW
    (:= (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (* (MASS (AT S
:BEGIN)) (R HYDROGEN) (T (AT S :BEGIN))))
on
   (V (AT S :BEGIN)) = 1
   (MASS (AT S :BEGIN)) = 0.04614
   (T (AT S :BEGIN)) = 533.15
   (R HYDROGEN) = 4124.18
Found (V (AT CAN :END)) = 1
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT CAN :END)))
Found (V (AT S :END)) = 1
using equality
    (:= (V (AT CAN :END)) (V (AT S :END)))
Found (P (AT S :END)) = 109064.52160938
using
    PV/T=P2V2/T2
    (:= (/ (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (T (AT S :BEGIN)))
(/ (* (P (AT S :END)) (V (AT S :END))) (T (AT S :END))))
on
   (V (AT S :BEGIN)) = 1
   (T (AT S :BEGIN)) = 533.15
   (T (AT S :END)) = 573.15
   (V (AT S :END)) = 1
   (P (AT S :BEGIN)) = 101452.93500138
Found (DELTA-P HTR) = 7611.586608
using
    DELTA-P-DEFINITION
    (:= (DELTA-P HTR) (- (P (AT S :END)) (P (AT S :BEGIN))))
```

```
on
   (P (AT S :BEGIN)) = 101452.93500138
   (P (AT S :END)) = 109064.52160938
```
;;; Finished <P: HB4.91B>

4.93 A closed rigid container has 6 kg of air at an initial pressure of 100 kPa and volume of 25 m^3. The air undergoes a process to a final pressure of 20 kPa. In what form (heat transfer or work) did the energy transfer take place? How much energy was transferred? Was it into or out of the system?

```
(add-problem-description :hb4.93
 :givens '((container (at can :begin))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (rigid (at can :begin))
           (nvalue (mass (at s :begin)) 6 kg)
           (substance-of (at s :begin) air)
           (nvalue (P (at s :begin)) 100 kPa)
           (nvalue (V (at s :begin)) 25 m^3)
           (contained-process mystery (at s :begin) (at s :end))
           (nvalue (P (at s :end)) 20 kPa)))

(add-problem-goal :hb4.93a
  :description :hb4.93
  :goal '(find (nvalue (Q mystery)))
 :answer '(-5004 kJ))

(add-problem-goal :hb4.93b
  :description :hb4.93
  :goal '(find (nvalue (work mystery)))
 :answer '(0 kJ))


;;; Answer-for :HB4.93A: -4993031.35888502
;;; Answer is correct! Given (-5004 KJ) =~ -4993.03135888502
;;; (NVALUE (Q MYSTERY) -4993031.35888502)
Found (T (AT S :BEGIN)) = 1250000/861
using
    IDEAL-GAS-LAW
    (:= (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (* (MASS (AT S
:BEGIN)) (R AIR) (T (AT S :BEGIN))))
on
   (MASS (AT S :BEGIN)) = 6
   (P (AT S :BEGIN)) = 100000
   (V (AT S :BEGIN)) = 25
   (R AIR) = 287
Found (V (AT CAN :BEGIN)) = 25
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT S :BEGIN)))
Found (V (AT CAN :END)) = 25
using equality
    (:= (V (AT CAN :BEGIN)) (V (AT CAN :END)))
Found (V (AT S :END)) = 25
using equality
```

```
    (:= (V (AT CAN :END)) (V (AT S :END)))
Found (T (AT S :END)) = 250000/861
using
    PV/T=P2V2/T2
    (:= (/ (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (T (AT S :BEGIN)))
(/ (* (P (AT S :END)) (V (AT S :END))) (T (AT S :END))))
on
   (P (AT S :BEGIN)) = 100000
   (V (AT S :BEGIN)) = 25
   (P (AT S :END)) = 20000
   (V (AT S :END)) = 25
   (T (AT S :BEGIN)) = 1250000/861
Found (MASS (AT S :END)) = 6
using
    IDEAL-GAS-LAW
    (:= (* (P (AT S :END)) (V (AT S :END))) (* (MASS (AT S :END)) (R
AIR) (T (AT S :END))))
on
   (P (AT S :END)) = 20000
   (V (AT S :END)) = 25
   (R AIR) = 287
   (T (AT S :END)) = 250000/861
Found (SPEC-U (AT S :END)) = 208042.973286876
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :END)) (* (CV AIR) (T (AT S :END))))
on
   (CV AIR) = 716.5
   (T (AT S :END)) = 250000/861
Found (U (AT S :END)) = 1248257.83972125
using
    SPEC-U-DEFINITION
    (:= (SPEC-U (AT S :END)) (/ (U (AT S :END)) (MASS (AT S :END))))
on
   (SPEC-U (AT S :END)) = 208042.973286876
   (MASS (AT S :END)) = 6
Found (ENERGY (AT S :END)) = 1248257.83972125
using equality
    (:= (ENERGY (AT S :END)) (U (AT S :END)))
Found (ENERGY-END MYSTERY) = 1248257.83972125
using equality
    (:= (ENERGY-END MYSTERY) (ENERGY (AT S :END)))
Found (SPEC-U (AT S :BEGIN)) = 1040214.86643438
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :BEGIN)) (* (CV AIR) (T (AT S :BEGIN))))
on
   (CV AIR) = 716.5
   (T (AT S :BEGIN)) = 1250000/861
Found (U (AT S :BEGIN)) = 6241289.19860627
using
    SPEC-U-DEFINITION
    (:= (SPEC-U (AT S :BEGIN)) (/ (U (AT S :BEGIN)) (MASS (AT S
:BEGIN))))
on
   (MASS (AT S :BEGIN)) = 6
```

```
   (SPEC-U (AT S :BEGIN)) = 1040214.86643438
Found (ENERGY (AT S :BEGIN)) = 6241289.19860627
using equality
    (:= (ENERGY (AT S :BEGIN)) (U (AT S :BEGIN)))
Found (ENERGY-BEGIN MYSTERY) = 6241289.19860627
using equality
    (:= (ENERGY-BEGIN MYSTERY) (ENERGY (AT S :BEGIN)))
Found (Q MYSTERY) = -4993031.35888502
using
    CONSERVATION-OF-ENERGY
    (:= (+ (Q MYSTERY) (ENERGY-BEGIN MYSTERY) (ENERGY-INLET MYSTERY))
(+ (ENERGY-END MYSTERY) (ENERGY-OUTLET MYSTERY) (WORK MYSTERY)))
on
   (WORK MYSTERY) = 0
   (ENERGY-OUTLET MYSTERY) = 0
   (ENERGY-INLET MYSTERY) = 0
   (ENERGY-BEGIN MYSTERY) = 6241289.19860627
   (ENERGY-END MYSTERY) = 1248257.83972125
;;; Finished <P: HB4.93A>
```

4.99 Helium in a rigid vessel initially at $T_1 = 20^{\circ}$C and $P_1 = 150$ kPa is cooled until the pressure is 100 kPa. Determine the work and heat transfer (kJ/kg) for the process.

```
(add-problem-description :hb4.99
  :givens '((container (at can :begin))
            (static-thermodynamic-stuff (at S :begin))
            (inside (at S :begin) (at can :begin))
            (rigid (at can :begin))
            (closed (at can :begin))
            (substance-of (at s :begin) helium)
            (nvalue (T (at s :begin)) 20 C)
            (nvalue (P (at s :begin)) 150 kPa)
            (cooling cool (at s :begin) (at s :end))
            (nvalue (P (at s :end)) 100 kPa)))

(add-problem-goal :hb4.99a
  :description :hb4.99
  :goal '(find (nvalue (spec-work cool)))
  :answer '(0))

(add-problem-goal :hb4.99b
  :description :hb4.99
  :goal '(find (nvalue (spec-q cool)))
  :answer '(-304.4 kj/kg))


;;; Answer-for :HB4.99B: -304446.046666667
;;; Answer is correct! Given (-304.4 KJ/KG) =~ -304.446046666667
;;; (NVALUE (SPEC-Q COOL) -304446.046666667)
Found (T (AT S :END)) = 195.433333333333
using
    PSPEC-V/T=P2SPEC-V2/T2-RIGID
```

```
    (:= (/ (P (AT S :BEGIN)) (T (AT S :BEGIN))) (/ (P (AT S :END)) (T
(AT S :END))))
on
   (T (AT S :BEGIN)) = 293.15
   (P (AT S :BEGIN)) = 150000
   (P (AT S :END)) = 100000
Found (SPEC-U (AT S :END)) = 608892.093333333
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :END)) (* (CV HELIUM) (T (AT S :END))))
on
   (CV HELIUM) = 3115.6
   (T (AT S :END)) = 195.433333333333
Found (SPEC-ENERGY (AT S :END)) = 608892.093333333
using equality
    (:= (SPEC-ENERGY (AT S :END)) (SPEC-U (AT S :END)))
Found (SPEC-ENERGY-END COOL) = 608892.093333333
using equality
    (:= (SPEC-ENERGY-END COOL) (SPEC-ENERGY (AT S :END)))
Found (SPEC-U (AT S :BEGIN)) = 913338.14
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :BEGIN)) (* (CV HELIUM) (T (AT S :BEGIN))))
on
   (T (AT S :BEGIN)) = 293.15
   (CV HELIUM) = 3115.6
Found (SPEC-ENERGY (AT S :BEGIN)) = 913338.14
using equality
    (:= (SPEC-ENERGY (AT S :BEGIN)) (SPEC-U (AT S :BEGIN)))
Found (SPEC-ENERGY-BEGIN COOL) = 913338.14
using equality
    (:= (SPEC-ENERGY-BEGIN COOL) (SPEC-ENERGY (AT S :BEGIN)))
Found (SPEC-Q COOL) = -304446.046666667
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q COOL) (SPEC-ENERGY-BEGIN COOL) (SPEC-ENERGY-INLET
COOL)) (+ (SPEC-ENERGY-END COOL) (SPEC-ENERGY-OUTLET COOL) (SPEC-WORK
COOL)))
on
   (SPEC-WORK COOL) = 0
   (SPEC-ENERGY-OUTLET COOL) = 0
   (SPEC-ENERGY-INLET COOL) = 0
   (SPEC-ENERGY-BEGIN COOL) = 913338.14
   (SPEC-ENERGY-END COOL) = 608892.093333333
;;; Finished <P: HB4.99B>
```

4.101 Nitrogen (2.5 kg) is contained in a frictionless piston-cylinder device at 30°C and 250 kPa. If there is a heat transfer until the total volume of N_2 is 1.2 m^3, find the work (kJ/kg) and total heat transfer in the process.

```
(add-problem-description :hb4.101
  :givens '((piston (at can :begin))
            (static-thermodynamic-stuff (at S :begin))
            (:NOT (use-superheated-tables (at S :begin)))
```

```
            (:NOT (use-superheated-tables (at S :end)))
            (inside (at S :begin) (at can :begin))
            (direction (at can :begin) :up)
            (substance-of (at s :begin) nitrogen)
            (nvalue (mass (at s :begin)) 2.5 kg)
            (nvalue (P (at s :begin)) 250 kPa)
            (nvalue (T (at s :begin)) 30 C)
            (heating htr (at s :begin) (at s :end))
            (nvalue (V (at s :end)) 1.2 m^3)))

(add-problem-goal :hb4.101a
  :description :hb4.101
  :goal '(find (nvalue (spec-work htr)))
  :answer '(30.08 kJ/kg))

(add-problem-goal :hb4.101b
  :description :hb4.101
  :goal '(find (nvalue (Q htr)))
  :answer '(263.5 kJ))


;;; Answer-for :HB4.101A: 30025.08
;;; Answer is correct! Given (30.08 KJ/KG) =~ 30.02508
;;; (NVALUE (SPEC-WORK HTR) 30025.08)
Found (V (AT S :BEGIN)) = 0.8997492
using
    IDEAL-GAS-LAW
    (:= (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (* (MASS (AT S
:BEGIN)) (R NITROGEN) (T (AT S :BEGIN))))
on
   (MASS (AT S :BEGIN)) = 2.5
   (P (AT S :BEGIN)) = 250000
   (T (AT S :BEGIN)) = 303.15
   (R NITROGEN) = 296.8
Found (P (AT S :END)) = 250000
using equality
    (:= (P (AT S :BEGIN)) (P (AT S :END)))
Found (T (AT S :END)) = 404.312668463612
using
    PV/T=P2V2/T2
    (:= (/ (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (T (AT S :BEGIN)))
(/ (* (P (AT S :END)) (V (AT S :END))) (T (AT S :END))))
on
   (P (AT S :BEGIN)) = 250000
   (T (AT S :BEGIN)) = 303.15
   (V (AT S :END)) = 1.2
   (P (AT S :END)) = 250000
   (V (AT S :BEGIN)) = 0.8997492
Found (SPEC-V (AT S :END)) = 0.48
using
    IDEAL-GAS-SPEC-VOLUME
    (:= (* (P (AT S :END)) (SPEC-V (AT S :END))) (* (R NITROGEN) (T
(AT S :END))))
on
   (P (AT S :END)) = 250000
   (R NITROGEN) = 296.8
```

```
   (T (AT S :END)) = 404.312668463612
Found (SPEC-V (AT S :BEGIN)) = 0.35989968
using
    IDEAL-GAS-SPEC-VOLUME
    (:= (* (P (AT S :BEGIN)) (SPEC-V (AT S :BEGIN))) (* (R NITROGEN)
(T (AT S :BEGIN))))
on
   (P (AT S :BEGIN)) = 250000
   (T (AT S :BEGIN)) = 303.15
   (R NITROGEN) = 296.8
Found (SPEC-WORK HTR) = 30025.08
using
    SPEC-WORK=PDV-ISOBARIC
    (:= (SPEC-WORK HTR) (* (P (AT S :BEGIN)) (- (SPEC-V (AT S :END))
(SPEC-V (AT S :BEGIN)))))
on
   (P (AT S :BEGIN)) = 250000
   (SPEC-V (AT S :BEGIN)) = 0.35989968
   (SPEC-V (AT S :END)) = 0.48
;;; Finished <P: HB4.101A>


;;; Answer-for :HB4.101B: 263427.588679245
;;; Answer is correct! Given (263.5 KJ) =~ 263.427588679245
;;; (NVALUE (Q HTR) 263427.588679245)
Found (V (AT S :BEGIN)) = 0.8997492
using
    IDEAL-GAS-LAW
    (:= (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (* (MASS (AT S
:BEGIN)) (R NITROGEN) (T (AT S :BEGIN))))
on
   (MASS (AT S :BEGIN)) = 2.5
   (P (AT S :BEGIN)) = 250000
   (T (AT S :BEGIN)) = 303.15
   (R NITROGEN) = 296.8
Found (WORK HTR) = 75062.7
using
    WORK=PDV-ISOBARIC
    (:= (WORK HTR) (* (P (AT S :BEGIN)) (- (V (AT S :END)) (V (AT S
:BEGIN)))))
on
   (P (AT S :BEGIN)) = 250000
   (V (AT S :END)) = 1.2
   (V (AT S :BEGIN)) = 0.8997492
Found (P (AT S :END)) = 250000
using equality
    (:= (P (AT S :BEGIN)) (P (AT S :END)))
Found (T (AT S :END)) = 404.312668463612
using
    PV/T=P2V2/T2
    (:= (/ (* (P (AT S :BEGIN)) (V (AT S :BEGIN))) (T (AT S :BEGIN)))
(/ (* (P (AT S :END)) (V (AT S :END))) (T (AT S :END))))
on
   (P (AT S :BEGIN)) = 250000
   (T (AT S :BEGIN)) = 303.15
   (V (AT S :END)) = 1.2
```

```
   (P (AT S :END)) = 250000
   (V (AT S :BEGIN)) = 0.8997492
Found (MASS (AT S :END)) = 2.5
using
    IDEAL-GAS-LAW
    (:= (* (P (AT S :END)) (V (AT S :END))) (* (MASS (AT S :END)) (R
NITROGEN) (T (AT S :END))))
on
   (V (AT S :END)) = 1.2
   (P (AT S :END)) = 250000
   (R NITROGEN) = 296.8
   (T (AT S :END)) = 404.312668463612
Found (SPEC-U (AT S :END)) = 301132.075471698
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :END)) (* (CV NITROGEN) (T (AT S :END))))
on
   (CV NITROGEN) = 744.8
   (T (AT S :END)) = 404.312668463612
Found (U (AT S :END)) = 752830.188679245
using
    SPEC-U-DEFINITION
    (:= (SPEC-U (AT S :END)) (/ (U (AT S :END)) (MASS (AT S :END))))
on
   (SPEC-U (AT S :END)) = 301132.075471698
   (MASS (AT S :END)) = 2.5
Found (ENERGY (AT S :END)) = 752830.188679245
using equality
    (:= (ENERGY (AT S :END)) (U (AT S :END)))
Found (ENERGY-END HTR) = 752830.188679245
using equality
    (:= (ENERGY-END HTR) (ENERGY (AT S :END)))
Found (SPEC-U (AT S :BEGIN)) = 225786.12
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :BEGIN)) (* (CV NITROGEN) (T (AT S :BEGIN))))
on
   (T (AT S :BEGIN)) = 303.15
   (CV NITROGEN) = 744.8
Found (U (AT S :BEGIN)) = 564465.3
using
    SPEC-U-DEFINITION
    (:= (SPEC-U (AT S :BEGIN)) (/ (U (AT S :BEGIN)) (MASS (AT S
:BEGIN))))
on
   (MASS (AT S :BEGIN)) = 2.5
   (SPEC-U (AT S :BEGIN)) = 225786.12
Found (ENERGY (AT S :BEGIN)) = 564465.3
using equality
    (:= (ENERGY (AT S :BEGIN)) (U (AT S :BEGIN)))
Found (ENERGY-BEGIN HTR) = 564465.3
using equality
    (:= (ENERGY-BEGIN HTR) (ENERGY (AT S :BEGIN)))
Found (Q HTR) = 263427.588679245
using
    CONSERVATION-OF-ENERGY
```

```
    (:= (+ (Q HTR) (ENERGY-BEGIN HTR) (ENERGY-INLET HTR)) (+ (ENERGY-
END HTR) (ENERGY-OUTLET HTR) (WORK HTR)))
on
   (ENERGY-OUTLET HTR) = 0
   (ENERGY-INLET HTR) = 0
   (ENERGY-BEGIN HTR) = 564465.3
   (ENERGY-END HTR) = 752830.188679245
   (WORK HTR) = 75062.7
;;; Finished <P: HB4.101B>
```

4.103 Shaft work (500 kJ/kg) is transferred to the air-filled frictionless piston-cylinder device shown. Determine the heat transfer (kJ/kg). The initial and final states of the air are T_1 = 200°C, P_1 = 400 kPa and T_2 = 250°C, respectively.

```
(add-problem :hb4.103
 :givens '((piston-with-block-fan
            (at can :begin) (at can :begin)
            (top (at can :begin)) (at F :begn))
           (static-thermodynamic-stuff (at S :begin))
           (inside (at S :begin) (at can :begin))
           (direction (at can :begin) :up)
           (substance-of (at s :begin) air)
           (nvalue (P (at s :begin)) 400 kPa)
           (nvalue (T (at s :begin)) 200 C)
           (contained-process spin (at s :begin) (at s :end))
           (nvalue (spec-work spin) 500 kJ/kg)
           (nvalue (T (at s :end)) 250 C))
 :goal '(find (nvalue (spec-q spin)))
 :answer '(-449.8 kJ/kg))


;;; Answer-for :HB4.103: 535825.0
;;; (NVALUE (SPEC-Q SPIN) 535825.0)
Found (SPEC-U (AT S :END)) = 374836.975
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :END)) (* (CV AIR) (T (AT S :END))))
on
   (T (AT S :END)) = 523.15
   (CV AIR) = 716.5
Found (SPEC-ENERGY (AT S :END)) = 374836.975
using equality
    (:= (SPEC-ENERGY (AT S :END)) (SPEC-U (AT S :END)))
Found (SPEC-ENERGY-END SPIN) = 374836.975
using equality
    (:= (SPEC-ENERGY-END SPIN) (SPEC-ENERGY (AT S :END)))
Found (SPEC-U (AT S :BEGIN)) = 339011.975
using
    IDEAL-GAS-INTERNAL-ENERGY
    (:= (SPEC-U (AT S :BEGIN)) (* (CV AIR) (T (AT S :BEGIN))))
on
   (T (AT S :BEGIN)) = 473.15
```

```
   (CV AIR) = 716.5
Found (SPEC-ENERGY (AT S :BEGIN)) = 339011.975
using equality
    (:= (SPEC-ENERGY (AT S :BEGIN)) (SPEC-U (AT S :BEGIN)))
Found (SPEC-ENERGY-BEGIN SPIN) = 339011.975
using equality
    (:= (SPEC-ENERGY-BEGIN SPIN) (SPEC-ENERGY (AT S :BEGIN)))
Found (SPEC-Q SPIN) = 535825.0
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q SPIN) (SPEC-ENERGY-BEGIN SPIN) (SPEC-ENERGY-INLET
SPIN)) (+ (SPEC-ENERGY-END SPIN) (SPEC-ENERGY-OUTLET SPIN) (SPEC-WORK
SPIN)))
on
   (SPEC-WORK SPIN) = 500000
   (SPEC-ENERGY-OUTLET SPIN) = 0
   (SPEC-ENERGY-INLET SPIN) = 0
   (SPEC-ENERGY-BEGIN SPIN) = 339011.975
   (SPEC-ENERGY-END SPIN) = 374836.975
;;; Finished <P: HB4.103>
```

4.115S A steam turbine is designed to operate at a mass flow rate of 1.5 kg/s. The inlet conditions are P_1 = 2 MPa, T_1= 400°C and $\mathbf{V}_1$ = 60 m/s; the outlet conditions are P_2= 0.1 MPa, x_2 = 0.98, and $\mathbf{V}_2$= 150 m/s. The change in elevation from inlet to outlet is a drop of 1 m, and the heat loss is 50 kW. Evaluate the power output of the turbine.

```
(add-problem :hb4.115
  :givens '((turbine tur (at s :begin) (at s :end))
            (complex-thermodynamic-stuff (at s :begin))
            (complex-thermodynamic-stuff (at s :end))
            (substance-of (at s :begin) water)
            (nvalue (P (at s :begin)) 2 MPa)
            (nvalue (T (at s :begin)) 400 C)
            (nvalue (velocity (at s :begin)) 60 m/s)
            (nvalue (height (at s :begin)) 2 m)
            (nvalue (mass (at s :begin)) 1.5 kg/s)
            (nvalue (P (at s :end)) 0.1 MPa)
            (nvalue (dryness (at s :end)) 0.98)
            (nvalue (velocity (at s :end)) 150 m/s)
            (nvalue (height (at s :end)) 1 m)
            (nvalue (Q tur) -50 kW))
  :goal '(find (nvalue (work tur)))
  :answer '(862.2 kw))


;;; Answer-for :HB4.115: 862167.4105
;;; Answer is correct! Given (862.2 KW) =~ 862.1674105
;;; (NVALUE (WORK TUR) 862167.4105)
Found (SPEC-HG (AT S :END)) = 2675100.0
using
    SATURATED-TABLE-P
on
```

```
   (P (AT S :END)) = 100000.0
Found (SPEC-HF (AT S :END)) = 417510.0
using
    SATURATED-TABLE-P
on
   (P (AT S :END)) = 100000.0
Found (SPEC-H (AT S :END)) = 2629948.2
using
    H-SATURATED-STUFF
    (:= (SPEC-H (AT S :END)) (+ (SPEC-HF (AT S :END)) (* (DRYNESS (AT
S :END)) (- (SPEC-HG (AT S :END)) (SPEC-HF (AT S :END))))))
on
   (DRYNESS (AT S :END)) = 0.98
   (SPEC-HF (AT S :END)) = 417510.0
   (SPEC-HG (AT S :END)) = 2675100.0
Found (SPEC-ENERGY (AT S :END)) = 2641208.007
using
    SS-THERMODYNAMIC-STUFF
    (:= (SPEC-ENERGY (AT S :END)) (+ (* (ACCELERATION GRAVITY)
(HEIGHT (AT S :END))) (/ (SQR (VELOCITY (AT S :END))) 2) (SPEC-H (AT
S :END))))
on
   (VELOCITY (AT S :END)) = 150
   (HEIGHT (AT S :END)) = 1
   (ACCELERATION GRAVITY) = 9.807
   (SPEC-H (AT S :END)) = 2629948.2
Found (SPEC-ENERGY-OUTLET TUR) = 2641208.007
using equality
    (:= (SPEC-ENERGY-OUTLET TUR) (SPEC-ENERGY (AT S :END)))
Found (SPEC-H (AT S :BEGIN)) = 3247500.0
using
    SUPERHEATED-P-T
on
   (P (AT S :BEGIN)) = 2000000
   (T (AT S :BEGIN)) = 673.15
Found (SPEC-ENERGY (AT S :BEGIN)) = 3249319.614
using
    SS-THERMODYNAMIC-STUFF
    (:= (SPEC-ENERGY (AT S :BEGIN)) (+ (* (ACCELERATION GRAVITY)
(HEIGHT (AT S :BEGIN))) (/ (SQR (VELOCITY (AT S :BEGIN))) 2) (SPEC-H
(AT S :BEGIN))))
on
   (VELOCITY (AT S :BEGIN)) = 60
   (HEIGHT (AT S :BEGIN)) = 2
   (ACCELERATION GRAVITY) = 9.807
   (SPEC-H (AT S :BEGIN)) = 3247500.0
Found (SPEC-ENERGY-INLET TUR) = 3249319.614
using equality
    (:= (SPEC-ENERGY-INLET TUR) (SPEC-ENERGY (AT S :BEGIN)))
Found (MASS-INLET TUR) = 1.5
using equality
    (:= (MASS-INLET TUR) (MASS (AT S :BEGIN)))
Found (SPEC-Q TUR) = -33333.3333333333
using
    Q-DEFINITION
    (:= (Q TUR) (* (SPEC-Q TUR) (MASS-INLET TUR)))
```

```
on
   (Q TUR) = -50000
   (MASS-INLET TUR) = 1.5
Found (SPEC-WORK TUR) = 574778.273666666
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q TUR) (SPEC-ENERGY-BEGIN TUR) (SPEC-ENERGY-INLET
TUR)) (+ (SPEC-ENERGY-END TUR) (SPEC-ENERGY-OUTLET TUR) (SPEC-WORK
TUR)))
on
   (SPEC-ENERGY-END TUR) = 0
   (SPEC-ENERGY-BEGIN TUR) = 0
   (SPEC-Q TUR) = -33333.3333333333
   (SPEC-ENERGY-INLET TUR) = 3249319.614
   (SPEC-ENERGY-OUTLET TUR) = 2641208.007
Found (WORK TUR) = 862167.4105
using
    WORK-DEFINITION
    (:= (WORK TUR) (* (SPEC-WORK TUR) (MASS-INLET TUR)))
on
   (MASS-INLET TUR) = 1.5
   (SPEC-WORK TUR) = 574778.273666666
;;; Finished <P: HB4.115>
```

4.117 Steam enters an adiabatic turbine as saturated vapor at a pressure of 2.5 MPa. It exists at $x_4 = 0.98$ and a pressure of 0.15 MPa. If m is 72 kg/s, what is the turbine power output?

```
(add-problem :hb4.117
 :givens '((turbine tur (at s :begin) (at s :end))
           (substance-of (at s :begin) water)
           (adiabatic tur)
           (nvalue (mass (at s :begin)) 72 kg/s)
           (saturated-vapor (at s :begin))
           (nvalue (P (at s :begin)) 2.5 Mpa)
           (saturated (at s :end))
           (nvalue (P (at s :end)) 0.15 Mpa)
           (nvalue (dryness (at s :end)) 0.98))
  :goal '(find (nvalue (work tur)))
  :answer '(11030 kW))


;;; Answer-for :HB4.117: 1.10393568E7
;;; Answer is correct! Given (11030 KW) =~ 11039.3568
;;; (NVALUE (WORK TUR) 1.10393568E7)
Found (SPEC-HG (AT S :END)) = 2693400.0
using
    SATURATED-TABLE-P
on
   (P (AT S :END)) = 150000.0
Found (SPEC-HF (AT S :END)) = 467180.0
using
    SATURATED-TABLE-P
on
```

```
   (P (AT S :END)) = 150000.0
Found (SPEC-H (AT S :END)) = 2648875.6
using
    H-SATURATED-STUFF
    (:= (SPEC-H (AT S :END)) (+ (SPEC-HF (AT S :END)) (* (DRYNESS (AT
S :END)) (- (SPEC-HG (AT S :END)) (SPEC-HF (AT S :END))))))
on
   (DRYNESS (AT S :END)) = 0.98
   (SPEC-HF (AT S :END)) = 467180.0
   (SPEC-HG (AT S :END)) = 2693400.0
Found (SPEC-ENERGY (AT S :END)) = 2648875.6
using equality
    (:= (SPEC-ENERGY (AT S :END)) (SPEC-H (AT S :END)))
Found (SPEC-ENERGY-OUTLET TUR) = 2648875.6
using equality
    (:= (SPEC-ENERGY-OUTLET TUR) (SPEC-ENERGY (AT S :END)))
Found (SPEC-HG (AT S :BEGIN)) = 2802200.0
using
    SATURATED-TABLE-P
on
   (P (AT S :BEGIN)) = 2500000.0
Found (SPEC-HF (AT S :BEGIN)) = 961980.0
using
    SATURATED-TABLE-P
on
   (P (AT S :BEGIN)) = 2500000.0
Found (SPEC-H (AT S :BEGIN)) = 2802200.0
using
    H-SATURATED-STUFF
    (:= (SPEC-H (AT S :BEGIN)) (+ (SPEC-HF (AT S :BEGIN)) (* (DRYNESS
(AT S :BEGIN)) (- (SPEC-HG (AT S :BEGIN)) (SPEC-HF (AT S :BEGIN))))))
on
   (DRYNESS (AT S :BEGIN)) = 1
   (SPEC-HF (AT S :BEGIN)) = 961980.0
   (SPEC-HG (AT S :BEGIN)) = 2802200.0
Found (SPEC-ENERGY (AT S :BEGIN)) = 2802200.0
using equality
    (:= (SPEC-ENERGY (AT S :BEGIN)) (SPEC-H (AT S :BEGIN)))
Found (SPEC-ENERGY-INLET TUR) = 2802200.0
using equality
    (:= (SPEC-ENERGY-INLET TUR) (SPEC-ENERGY (AT S :BEGIN)))
Found (SPEC-WORK TUR) = 153324.4
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q TUR) (SPEC-ENERGY-BEGIN TUR) (SPEC-ENERGY-INLET
TUR)) (+ (SPEC-ENERGY-END TUR) (SPEC-ENERGY-OUTLET TUR) (SPEC-WORK
TUR)))
on
   (SPEC-Q TUR) = 0
   (SPEC-ENERGY-END TUR) = 0
   (SPEC-ENERGY-BEGIN TUR) = 0
   (SPEC-ENERGY-INLET TUR) = 2802200.0
   (SPEC-ENERGY-OUTLET TUR) = 2648875.6
Found (MASS-INLET TUR) = 72
using equality
    (:= (MASS-INLET TUR) (MASS (AT S :BEGIN)))
```

```
Found (WORK TUR) = 1.10393568E7
using
    WORK-DEFINITION
    (:= (WORK TUR) (* (SPEC-WORK TUR) (MASS-INLET TUR)))
on
   (MASS-INLET TUR) = 72
   (SPEC-WORK TUR) = 153324.4
;;; Finished <P: HB4.117>
```

4.119 Steam enters a turbine at a temperature of 300°C and a pressure of 0.4 MPa. If it leaves as a saturated vapor at 0.03 MPa, what is the change in enthalpy between the two state points?

```
(add-problem :hb4.119
 :givens '((turbine tur (at s :begin) (at s :end))
           (substance-of (at s :begin) water)
           (nvalue (P (at s :begin)) 0.4 Mpa)
           (nvalue (T (at s :begin)) 300 C)
           (saturated-vapor (at s :end))
           (nvalue (P (at s :end)) 0.03 Mpa))
 :goal '(find (nvalue (delta-spec-h tur)))
 :answer '(-441.7 kJ/kg))


;;; Answer-for :HB4.119: -441700.0
;;; Answer is correct! Given (-441.7 KJ/KG) =~ -441.7
;;; (NVALUE (DELTA-SPEC-H TUR) -441700.0)
Found (SPEC-H (AT S :BEGIN)) = 3066300.0
using
    SUPERHEATED-P-T
on
   (P (AT S :BEGIN)) = 400000.0
   (T (AT S :BEGIN)) = 573.15
Found (SPEC-HG (AT S :END)) = 2624600.0
using
    SATURATED-TABLE-P
on
   (P (AT S :END)) = 30000.0
Found (SPEC-HF (AT S :END)) = 289280.0
using
    SATURATED-TABLE-P
on
   (P (AT S :END)) = 30000.0
Found (SPEC-H (AT S :END)) = 2624600.0
using
    H-SATURATED-STUFF
    (:= (SPEC-H (AT S :END)) (+ (SPEC-HF (AT S :END)) (* (DRYNESS (AT
S :END)) (- (SPEC-HG (AT S :END)) (SPEC-HF (AT S :END))))))
on
   (DRYNESS (AT S :END)) = 1
   (SPEC-HF (AT S :END)) = 289280.0
   (SPEC-HG (AT S :END)) = 2624600.0
Found (DELTA-SPEC-H TUR) = -441700.0
using
```

```
    DELTA-SPEC-H-DEFINITION
    (:= (DELTA-SPEC-H TUR) (- (SPEC-H (AT S :END)) (SPEC-H (AT S
:BEGIN))))
on
   (SPEC-H (AT S :END)) = 2624600.0
   (SPEC-H (AT S :BEGIN)) = 3066300.0
;;; Finished <P: HB4.119>
```

4.121 A nonadiabatic steam turbine operates as shown. Determine the rate of heat transfer (kW).

```
(add-problem :hb4.121
 :givens '((turbine tur (at s :begin) (at s :end))
           (substance-of (at s :begin) water)
           (nvalue (P (at s :begin)) 6 Mpa)
           (nvalue (T (at s :begin)) 500 C)
           (nvalue (mass (at s :begin)) 2 kg/s)
           (nvalue (work tur) 1500 kW)

           (nvalue (P (at s :end)) 40 kPa)
           (nvalue (dryness (at s :end)) 0.96)
           )
  :goal '(find (nvalue (q tur)))
  :answer '(-257.8 kW))


;;; Answer-for :HB4.121: -257877.600000001
;;; Answer is correct! Given (-257.8 KW) =~ -257.877600000001
;;; (NVALUE (Q TUR) -257877.600000001)
Found (MASS-INLET TUR) = 2
using equality
    (:= (MASS-INLET TUR) (MASS (AT S :BEGIN)))
Found (MASS-OUTLET TUR) = 2
using
    CONSERVATION-OF-MASS
    (:= (+ (MASS-BEGIN TUR) (MASS-INLET TUR)) (+ (MASS-END TUR)
(MASS-OUTLET TUR)))
on
   (MASS-END TUR) = 0
   (MASS-BEGIN TUR) = 0
   (MASS-INLET TUR) = 2
Found (MASS (AT S :END)) = 2
using equality
    (:= (MASS-OUTLET TUR) (MASS (AT S :END)))
Found (SPEC-HG (AT S :END)) = 2636100.0
using
    SATURATED-TABLE-P
on
   (P (AT S :END)) = 40000
Found (SPEC-HF (AT S :END)) = 317630.0
using
    SATURATED-TABLE-P
on
   (P (AT S :END)) = 40000
```

```
Found (SPEC-H (AT S :END)) = 2543361.2
using
    H-SATURATED-STUFF
    (:= (SPEC-H (AT S :END)) (+ (SPEC-HF (AT S :END)) (* (DRYNESS (AT
S :END)) (- (SPEC-HG (AT S :END)) (SPEC-HF (AT S :END))))))
on
   (DRYNESS (AT S :END)) = 0.96
   (SPEC-HF (AT S :END)) = 317630.0
   (SPEC-HG (AT S :END)) = 2636100.0
Found (H (AT S :END)) = 5086722.4
using
    SPEC-H-DEFINITION
    (:= (SPEC-H (AT S :END)) (/ (H (AT S :END)) (MASS (AT S :END))))
on
   (SPEC-H (AT S :END)) = 2543361.2
   (MASS (AT S :END)) = 2
Found (ENERGY (AT S :END)) = 5086722.4
using equality
    (:= (ENERGY (AT S :END)) (H (AT S :END)))
Found (ENERGY-OUTLET TUR) = 5086722.4
using equality
    (:= (ENERGY-OUTLET TUR) (ENERGY (AT S :END)))
Found (SPEC-H (AT S :BEGIN)) = 3422300.0
using
    SUPERHEATED-P-T
on
   (P (AT S :BEGIN)) = 6000000
   (T (AT S :BEGIN)) = 773.15
Found (H (AT S :BEGIN)) = 6844600.0
using
    SPEC-H-DEFINITION
    (:= (SPEC-H (AT S :BEGIN)) (/ (H (AT S :BEGIN)) (MASS (AT S
:BEGIN))))
on
   (MASS (AT S :BEGIN)) = 2
   (SPEC-H (AT S :BEGIN)) = 3422300.0
Found (ENERGY (AT S :BEGIN)) = 6844600.0
using equality
    (:= (ENERGY (AT S :BEGIN)) (H (AT S :BEGIN)))
Found (ENERGY-INLET TUR) = 6844600.0
using equality
    (:= (ENERGY-INLET TUR) (ENERGY (AT S :BEGIN)))
Found (Q TUR) = -257877.600000001
using
    CONSERVATION-OF-ENERGY
    (:= (+ (Q TUR) (ENERGY-BEGIN TUR) (ENERGY-INLET TUR)) (+ (ENERGY-
END TUR) (ENERGY-OUTLET TUR) (WORK TUR)))
on
   (WORK TUR) = 1500000
   (ENERGY-END TUR) = 0
   (ENERGY-BEGIN TUR) = 0
   (ENERGY-INLET TUR) = 6844600.0
   (ENERGY-OUTLET TUR) = 5086722.4
;;; Finished <P: HB4.121>
```

4.123 Determine the work (kJ/kg) output of the adiabatic steam turbine operating as shown.

```
(add-problem :hb4.123
 :givens '((turbine tur (at s :begin) (at s :end))
           (adiabatic tur)
           (substance-of (at s :begin) water)
           (nvalue (P (at s :begin)) 1 Mpa)
           (nvalue (T (at s :begin)) 600 C)
           (nvalue (P (at s :end)) 40 kPa)
           (nvalue (T (at s :end)) 150 C))
  :goal '(find (nvalue (spec-work tur)))
  :answer '(917.7 kW/kg))


;;; Answer-for :HB4.123: 917700.0
;;; Answer is correct! Given (917.7 KW/KG) =~ 917.7
;;; (NVALUE (SPEC-WORK TUR) 917700.0)
Found (SPEC-H (AT S :END)) = 2780400.0
using
    SUPERHEATED-P-T
on
   (P (AT S :END)) = 40000
   (T (AT S :END)) = 423.15
Found (SPEC-ENERGY (AT S :END)) = 2780400.0
using equality
    (:= (SPEC-ENERGY (AT S :END)) (SPEC-H (AT S :END)))
Found (SPEC-ENERGY-OUTLET TUR) = 2780400.0
using equality
    (:= (SPEC-ENERGY-OUTLET TUR) (SPEC-ENERGY (AT S :END)))
Found (SPEC-H (AT S :BEGIN)) = 3698100.0
using
    SUPERHEATED-P-T
on
   (P (AT S :BEGIN)) = 1000000
   (T (AT S :BEGIN)) = 873.15
Found (SPEC-ENERGY (AT S :BEGIN)) = 3698100.0
using equality
    (:= (SPEC-ENERGY (AT S :BEGIN)) (SPEC-H (AT S :BEGIN)))
Found (SPEC-ENERGY-INLET TUR) = 3698100.0
using equality
    (:= (SPEC-ENERGY-INLET TUR) (SPEC-ENERGY (AT S :BEGIN)))
Found (SPEC-WORK TUR) = 917700.0
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q TUR) (SPEC-ENERGY-BEGIN TUR) (SPEC-ENERGY-INLET
TUR)) (+ (SPEC-ENERGY-END TUR) (SPEC-ENERGY-OUTLET TUR) (SPEC-WORK
TUR)))
on
   (SPEC-Q TUR) = 0
   (SPEC-ENERGY-END TUR) = 0
   (SPEC-ENERGY-BEGIN TUR) = 0
   (SPEC-ENERGY-INLET TUR) = 3698100.0
   (SPEC-ENERGY-OUTLET TUR) = 2780400.0
;;; Finished <P: HB4.123>
```

4.125 Determine the power output (kW) of the air turbine operating as shown.

```
(add-problem :hb4.125
 :givens '((turbine tur (at s :begin) (at s :end))
           (substance-of (at s :begin) AIR)
           (nvalue (P (at s :begin)) 2 Mpa)
           (nvalue (T (at s :begin)) 600 C)
           (nvalue (mass (at s :begin)) 0.1 kg/s)

           (nvalue (q tur) -6 kW)
           (nvalue (P (at s :end)) 101.3 kPa)
           (nvalue (T (at s :end)) 100 C))
  :goal '(find (nvalue (work tur)))
  :answer '(44.26 kW))


;;; Answer-for :HB4.125: 44175.0
;;; Answer is correct! Given (44.26 KW) =~ 44.175
;;; (NVALUE (WORK TUR) 44175.0)
Found (SPEC-H (AT S :END)) = 374456.025
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :END)) (* (CP AIR) (T (AT S :END))))
on
   (T (AT S :END)) = 373.15
   (CP AIR) = 1003.5
Found (SPEC-ENERGY (AT S :END)) = 374456.025
using equality
    (:= (SPEC-ENERGY (AT S :END)) (SPEC-H (AT S :END)))
Found (SPEC-ENERGY-OUTLET TUR) = 374456.025
using equality
    (:= (SPEC-ENERGY-OUTLET TUR) (SPEC-ENERGY (AT S :END)))
Found (SPEC-H (AT S :BEGIN)) = 876206.025
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :BEGIN)) (* (CP AIR) (T (AT S :BEGIN))))
on
   (T (AT S :BEGIN)) = 873.15
   (CP AIR) = 1003.5
Found (SPEC-ENERGY (AT S :BEGIN)) = 876206.025
using equality
    (:= (SPEC-ENERGY (AT S :BEGIN)) (SPEC-H (AT S :BEGIN)))
Found (SPEC-ENERGY-INLET TUR) = 876206.025
using equality
    (:= (SPEC-ENERGY-INLET TUR) (SPEC-ENERGY (AT S :BEGIN)))
Found (MASS-INLET TUR) = 0.1
using equality
    (:= (MASS-INLET TUR) (MASS (AT S :BEGIN)))
Found (SPEC-Q TUR) = -60000.0
using
    Q-DEFINITION
    (:= (Q TUR) (* (SPEC-Q TUR) (MASS-INLET TUR)))
on
   (Q TUR) = -6000
```

```
   (MASS-INLET TUR) = 0.1
Found (SPEC-WORK TUR) = 441750.0
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q TUR) (SPEC-ENERGY-BEGIN TUR) (SPEC-ENERGY-INLET
TUR)) (+ (SPEC-ENERGY-END TUR) (SPEC-ENERGY-OUTLET TUR) (SPEC-WORK
TUR)))
on
   (SPEC-ENERGY-END TUR) = 0
   (SPEC-ENERGY-BEGIN TUR) = 0
   (SPEC-Q TUR) = -60000.0
   (SPEC-ENERGY-INLET TUR) = 876206.025
   (SPEC-ENERGY-OUTLET TUR) = 374456.025
Found (WORK TUR) = 44175.0
using
    WORK-DEFINITION
    (:= (WORK TUR) (* (SPEC-WORK TUR) (MASS-INLET TUR)))
on
   (MASS-INLET TUR) = 0.1
   (SPEC-WORK TUR) = 441750.0
;;; Finished <P: HB4.125>
```

4.127 Determine the work (kJ/kg) required to operate the adiabatic helium compressor operating as shown.

```
(add-problem :hb4.127
 :givens '((turbine tur (at s :begin) (at s :end))
           (substance-of (at s :begin) HELIUM)
           (adiabatic tur)
           (nvalue (P (at s :begin)) 40 kPa)
           (nvalue (T (at s :begin)) 150 C)
           (nvalue (P (at s :end)) 1.0 MPa)
           (nvalue (T (at s :end)) 550 C))
  :goal '(find (nvalue (spec-work tur)))
  :answer '(-2077 kW/kg))


;;; Answer-for :HB4.127: -2077040.0
;;; Answer is correct! Given (-2077 KW/KG) =~ -2077.04
;;; (NVALUE (SPEC-WORK TUR) -2077040.0)
Found (SPEC-H (AT S :END)) = 4274288.69
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :END)) (* (CP HELIUM) (T (AT S :END))))
on
   (T (AT S :END)) = 823.15
   (CP HELIUM) = 5192.6
Found (SPEC-ENERGY (AT S :END)) = 4274288.69
using equality
    (:= (SPEC-ENERGY (AT S :END)) (SPEC-H (AT S :END)))
Found (SPEC-ENERGY-OUTLET TUR) = 4274288.69
using equality
    (:= (SPEC-ENERGY-OUTLET TUR) (SPEC-ENERGY (AT S :END)))
Found (SPEC-H (AT S :BEGIN)) = 2197248.69
```

```
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :BEGIN)) (* (CP HELIUM) (T (AT S :BEGIN))))
on
   (T (AT S :BEGIN)) = 423.15
   (CP HELIUM) = 5192.6
Found (SPEC-ENERGY (AT S :BEGIN)) = 2197248.69
using equality
    (:= (SPEC-ENERGY (AT S :BEGIN)) (SPEC-H (AT S :BEGIN)))
Found (SPEC-ENERGY-INLET TUR) = 2197248.69
using equality
    (:= (SPEC-ENERGY-INLET TUR) (SPEC-ENERGY (AT S :BEGIN)))
Found (SPEC-WORK TUR) = -2077040.0
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q TUR) (SPEC-ENERGY-BEGIN TUR) (SPEC-ENERGY-INLET
TUR)) (+ (SPEC-ENERGY-END TUR) (SPEC-ENERGY-OUTLET TUR) (SPEC-WORK
TUR)))
on
   (SPEC-Q TUR) = 0
   (SPEC-ENERGY-END TUR) = 0
   (SPEC-ENERGY-BEGIN TUR) = 0
   (SPEC-ENERGY-INLET TUR) = 2197248.69
   (SPEC-ENERGY-OUTLET TUR) = 4274288.69
;;; Finished <P: HB4.127>
```

4.129 A compressor is to be purchased for the new mechanical engineering building. It must compress air from atmospheric pressure and 25°C to 10 atm and 600°C; and the outlet velocity from the compressor must not exceed 10 m/s. Assume the compressor to be adiabatic and frictionless.

(*a*) How much work is required for each kilogram of air that is compressed?

(*b*) What power is required to drive the compressor if 2 kg/s of air is to be compressed?

```
(add-problem-goal :hb4.129a
  :description :hb4.129
  :goal '(find (nvalue (spec-work comp)))
  :answer '(-605 kW/kg))

(add-problem-goal :hb4.129b
  :description :hb4.129
  :extras '((nvalue (mass (at s :begin)) 2 kg/s))
  :goal '(find (nvalue (work comp)))
  :answer '(-1210 kW))

;;; Answer-for :HB4.129A: -604643.075
;;; Answer is correct! Given (-605 KW/KG) =~ -604.643075
;;; (NVALUE (SPEC-WORK COMP) -604643.075)
Found (SPEC-H (AT S :END)) = 902925.675
using
```

```
    IDEAL-T-LOOKUP
on
   (T (AT S :END)) = 873.15
Found (SPEC-ENERGY (AT S :END)) = 902975.675
using
    SS-THERMODYNAMIC-STUFF
    (:= (SPEC-ENERGY (AT S :END)) (+ (/ (SQR (VELOCITY (AT S :END)))
2) (SPEC-H (AT S :END))))
on
   (VELOCITY (AT S :END)) = 10
   (SPEC-H (AT S :END)) = 902925.675
Found (SPEC-ENERGY-OUTLET COMP) = 902975.675
using equality
    (:= (SPEC-ENERGY-OUTLET COMP) (SPEC-ENERGY (AT S :END)))
Found (SPEC-H (AT S :BEGIN)) = 298332.6
using
    IDEAL-T-LOOKUP
on
   (T (AT S :BEGIN)) = 298.15
Found (SPEC-ENERGY (AT S :BEGIN)) = 298332.6
using equality
    (:= (SPEC-ENERGY (AT S :BEGIN)) (SPEC-H (AT S :BEGIN)))
Found (SPEC-ENERGY-INLET COMP) = 298332.6
using equality
    (:= (SPEC-ENERGY-INLET COMP) (SPEC-ENERGY (AT S :BEGIN)))
Found (SPEC-WORK COMP) = -604643.075
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q COMP) (SPEC-ENERGY-BEGIN COMP) (SPEC-ENERGY-INLET
COMP)) (+ (SPEC-ENERGY-END COMP) (SPEC-ENERGY-OUTLET COMP) (SPEC-WORK
COMP)))
on
   (SPEC-Q COMP) = 0
   (SPEC-ENERGY-END COMP) = 0
   (SPEC-ENERGY-BEGIN COMP) = 0
   (SPEC-ENERGY-INLET COMP) = 298332.6
   (SPEC-ENERGY-OUTLET COMP) = 902975.675
;;; Finished <P: HB4.129A>


;;; Answer-for :HB4.129B: -1209286.15
;;; Answer is correct! Given (-1210 KW) =~ -1209.28615
;;; (NVALUE (WORK COMP) -1209286.15)
Found (SPEC-H (AT S :END)) = 902925.675
using
    IDEAL-T-LOOKUP
on
   (T (AT S :END)) = 873.15
Found (SPEC-ENERGY (AT S :END)) = 902975.675
using
    SS-THERMODYNAMIC-STUFF
    (:= (SPEC-ENERGY (AT S :END)) (+ (/ (SQR (VELOCITY (AT S :END)))
2) (SPEC-H (AT S :END))))
on
   (VELOCITY (AT S :END)) = 10
   (SPEC-H (AT S :END)) = 902925.675
```

```
Found (SPEC-ENERGY-OUTLET COMP) = 902975.675
using equality
    (:= (SPEC-ENERGY-OUTLET COMP) (SPEC-ENERGY (AT S :END)))
Found (SPEC-H (AT S :BEGIN)) = 298332.6
using
    IDEAL-T-LOOKUP
on
   (T (AT S :BEGIN)) = 298.15
Found (SPEC-ENERGY (AT S :BEGIN)) = 298332.6
using equality
    (:= (SPEC-ENERGY (AT S :BEGIN)) (SPEC-H (AT S :BEGIN)))
Found (SPEC-ENERGY-INLET COMP) = 298332.6
using equality
    (:= (SPEC-ENERGY-INLET COMP) (SPEC-ENERGY (AT S :BEGIN)))
Found (SPEC-WORK COMP) = -604643.075
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q COMP) (SPEC-ENERGY-BEGIN COMP) (SPEC-ENERGY-INLET
COMP)) (+ (SPEC-ENERGY-END COMP) (SPEC-ENERGY-OUTLET COMP) (SPEC-WORK
COMP)))
on
   (SPEC-Q COMP) = 0
   (SPEC-ENERGY-END COMP) = 0
   (SPEC-ENERGY-BEGIN COMP) = 0
   (SPEC-ENERGY-INLET COMP) = 298332.6
   (SPEC-ENERGY-OUTLET COMP) = 902975.675
Found (MASS-INLET COMP) = 2
using equality
    (:= (MASS-INLET COMP) (MASS (AT S :BEGIN)))
Found (WORK COMP) = -1209286.15
using
    WORK-DEFINITION
    (:= (WORK COMP) (* (SPEC-WORK COMP) (MASS-INLET COMP)))
on
   (MASS-INLET COMP) = 2
   (SPEC-WORK COMP) = -604643.075
;;; Finished <P: HB4.129B>
```

4.131 Steam enters an isothermal compressor at 400°C and 0.1013 MPa. If the exit pressure is 10 MPa, determine the change in enthalpy.

```
(add-problem :hb4.131
 :givens '((compressor comp (at s :begin) (at s :end))
           (substance-of (at s :begin) water)
           (isothermal comp)
           (substance-of (at s :begin) water)
           (nvalue (P (at s :begin)) 101.3 kPa)
           (nvalue (T (at s :begin)) 400 C)
           (nvalue (P (at s :end)) 10 MPa))
  :goal '(find (nvalue (delta-spec-h comp)))
  :answer '(-181.9 kJ/kg))


;;; Answer-for :HB4.131: -181879.2
```

```
;;; Answer is correct! Given (-181.9 KJ/KG) =~ -181.8792
;;; (NVALUE (DELTA-SPEC-H COMP) -181879.2)
Found (SPEC-H (AT S :BEGIN)) = 3277979.2
using
    SUPERHEATED-P-T
on
   (P (AT S :BEGIN)) = 101300.0
   (T (AT S :BEGIN)) = 673.15
Found (T (AT S :END)) = 673.15
using equality
    (:= (T (AT S :BEGIN)) (T (AT S :END)))
Found (SPEC-H (AT S :END)) = 3096100.0
using
    SUPERHEATED-P-T
on
   (T (AT S :END)) = 673.15
   (P (AT S :END)) = 10000000
Found (DELTA-SPEC-H COMP) = -181879.2
using
    DELTA-SPEC-H-DEFINITION
    (:= (DELTA-SPEC-H COMP) (- (SPEC-H (AT S :END)) (SPEC-H (AT S
:BEGIN))))
on
   (SPEC-H (AT S :END)) = 3096100.0
   (SPEC-H (AT S :BEGIN)) = 3277979.2
;;; Finished <P: HB4.131>
```

4.135 A nonadiabatic air compressor operates as shown. What is the exit temperature?

```
(add-problem :hb4.135
  :givens '((compressor comp (at s :begin) (at s :end))
            (substance-of (at s :begin) AIR)
            (nvalue (P (at s :begin)) 0.3 Mpa)
            (nvalue (T (at s :begin)) 127 C)
            (nvalue (spec-work comp) -350 kW/kg)
            (nvalue (spec-q comp) -25 kJ/kg)
            (nvalue (P (at s :end)) 4 MPa))
  :goal '(find (nvalue (T (at s :end))))
  :answer '(448.3 C))


;;; Answer-for :HB4.135: 724.016467364225
;;; Answer is correct! Given (448.3 C) =~ 450.866467364225
;;; (NVALUE (T (AT S :END)) 724.016467364225)
Found (SPEC-H (AT S :BEGIN)) = 401550.525
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :BEGIN)) (* (CP AIR) (T (AT S :BEGIN))))
on
   (T (AT S :BEGIN)) = 400.15
   (CP AIR) = 1003.5
Found (SPEC-ENERGY (AT S :BEGIN)) = 401550.525
using equality
```

```
    (:= (SPEC-ENERGY (AT S :BEGIN)) (SPEC-H (AT S :BEGIN)))
Found (SPEC-ENERGY-INLET COMP) = 401550.525
using equality
    (:= (SPEC-ENERGY-INLET COMP) (SPEC-ENERGY (AT S :BEGIN)))
Found (SPEC-ENERGY-OUTLET COMP) = 726550.525
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q COMP) (SPEC-ENERGY-BEGIN COMP) (SPEC-ENERGY-INLET
COMP)) (+ (SPEC-ENERGY-END COMP) (SPEC-ENERGY-OUTLET COMP) (SPEC-WORK
COMP)))
on
   (SPEC-WORK COMP) = -350000
   (SPEC-Q COMP) = -25000
   (SPEC-ENERGY-END COMP) = 0
   (SPEC-ENERGY-BEGIN COMP) = 0
   (SPEC-ENERGY-INLET COMP) = 401550.525
Found (SPEC-ENERGY (AT S :END)) = 726550.525
using equality
    (:= (SPEC-ENERGY-OUTLET COMP) (SPEC-ENERGY (AT S :END)))
Found (SPEC-H (AT S :END)) = 726550.525
using equality
    (:= (SPEC-ENERGY (AT S :END)) (SPEC-H (AT S :END)))
Found (T (AT S :END)) = 724.016467364225
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :END)) (* (CP AIR) (T (AT S :END))))
on
   (CP AIR) = 1003.5
   (SPEC-H (AT S :END)) = 726550.525
;;; Finished <P: HB4.135>
```

4.137 An air compressor requires a power input of 100 kW to take air at 25°C and 1 atm and compress it adiabatically to a final pressure of 20 atm and a final temperature of 400°C.

(a) What mass flow rate of air is being compressed (kg/s)?

(b) What is the work produced by the compressor?

```
(add-problem-description :hb4.137
 :givens '((compressor comp (at s :begin) (at s :end))
           (substance-of (at s :begin) AIR)
           (nvalue (work comp) -100 kW)
           (nvalue (P (at s :begin)) 101.3 kPa)
           (nvalue (T (at s :begin)) 25 C)
           (adiabatic comp)
           (nvalue (P (at s :end)) 2026 kPa)
           (nvalue (T (at s :end)) 400 C)))

(add-problem-goal :hb4.137a
  :description :hb4.137
  :goal '(find (nvalue (mass (at s :begin))))
  :answer '(0.258 kg/s))
```

```
(add-problem-goal :hb4.137b
  :description :hb4.137
  :goal '(find (nvalue (work comp)))
  :answer '(-100 kW))


;;; Answer-for :HB4.137A: 0.265736588606544
;;; Answer is correct! Given (0.258 KG/S) =~ 0.265736588606544
;;; (NVALUE (MASS (AT S :BEGIN)) 0.265736588606544)
Found (SPEC-H (AT S :END)) = 675506.025
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :END)) (* (CP AIR) (T (AT S :END))))
on
   (T (AT S :END)) = 673.15
   (CP AIR) = 1003.5
Found (SPEC-ENERGY (AT S :END)) = 675506.025
using equality
    (:= (SPEC-ENERGY (AT S :END)) (SPEC-H (AT S :END)))
Found (SPEC-ENERGY-OUTLET COMP) = 675506.025
using equality
    (:= (SPEC-ENERGY-OUTLET COMP) (SPEC-ENERGY (AT S :END)))
Found (SPEC-H (AT S :BEGIN)) = 299193.525
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :BEGIN)) (* (CP AIR) (T (AT S :BEGIN))))
on
   (T (AT S :BEGIN)) = 298.15
   (CP AIR) = 1003.5
Found (SPEC-ENERGY (AT S :BEGIN)) = 299193.525
using equality
    (:= (SPEC-ENERGY (AT S :BEGIN)) (SPEC-H (AT S :BEGIN)))
Found (SPEC-ENERGY-INLET COMP) = 299193.525
using equality
    (:= (SPEC-ENERGY-INLET COMP) (SPEC-ENERGY (AT S :BEGIN)))
Found (SPEC-WORK COMP) = -376312.5
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q COMP) (SPEC-ENERGY-BEGIN COMP) (SPEC-ENERGY-INLET
COMP)) (+ (SPEC-ENERGY-END COMP) (SPEC-ENERGY-OUTLET COMP) (SPEC-WORK
COMP)))
on
   (SPEC-Q COMP) = 0
   (SPEC-ENERGY-END COMP) = 0
   (SPEC-ENERGY-BEGIN COMP) = 0
   (SPEC-ENERGY-INLET COMP) = 299193.525
   (SPEC-ENERGY-OUTLET COMP) = 675506.025
Found (MASS-INLET COMP) = 0.265736588606544
using
    WORK-DEFINITION
    (:= (WORK COMP) (* (SPEC-WORK COMP) (MASS-INLET COMP)))
on
   (WORK COMP) = -100000
   (SPEC-WORK COMP) = -376312.5
Found (MASS (AT S :BEGIN)) = 0.265736588606544
```

```
using equality
    (:= (MASS-INLET COMP) (MASS (AT S :BEGIN)))
;;; Finished <P: HB4.137A>
```

4.413 Steam enters an isobaric device with a quality of 100 percent and a pressure of 1.5 MPa. If the exit temperature is 350°C, determine the change in enthalpy.

```
(add-problem :hb4.143
 :givens '((cycle-process dev (at s :begin) (at s :end))
           (substance-of (at s :begin) water)
           (isobaric dev)
           (nvalue (P (at s :begin)) 1.5 MPa)
           (nvalue (dryness (at s :begin)) 1)
           (nvalue (T (at s :end)) 350 C))
  :goal '(find (nvalue (delta-spec-h dev)))
  :answer '(355.6 kJ/kg))

;;; Answer-for :HB4.143: 355450.0
;;; Answer is correct! Given (355.6 KJ/KG) =~ 355.45
;;; (NVALUE (DELTA-SPEC-H DEV) 355450.0)
Found (SPEC-HG (AT S :BEGIN)) = 2791500.0
using
    SATURATED-TABLE-P
on
   (P (AT S :BEGIN)) = 1500000.0
Found (SPEC-HF (AT S :BEGIN)) = 844860.0
using
    SATURATED-TABLE-P
on
   (P (AT S :BEGIN)) = 1500000.0
Found (SPEC-H (AT S :BEGIN)) = 2791500.0
using
    H-SATURATED-STUFF
    (:= (SPEC-H (AT S :BEGIN)) (+ (SPEC-HF (AT S :BEGIN)) (* (DRYNESS
(AT S :BEGIN)) (- (SPEC-HG (AT S :BEGIN)) (SPEC-HF (AT S :BEGIN))))))
on
   (DRYNESS (AT S :BEGIN)) = 1
   (SPEC-HF (AT S :BEGIN)) = 844860.0
   (SPEC-HG (AT S :BEGIN)) = 2791500.0
Found (P (AT S :END)) = 1500000.0
using equality
    (:= (P (AT S :BEGIN)) (P (AT S :END)))
Found (SPEC-H (AT S :END)) = 3146950.0
using
    SUPERHEATED-P-T
on
   (P (AT S :END)) = 1500000.0
   (T (AT S :END)) = 623.15
Found (DELTA-SPEC-H DEV) = 355450.0
using
    DELTA-SPEC-H-DEFINITION
    (:= (DELTA-SPEC-H DEV) (- (SPEC-H (AT S :END)) (SPEC-H (AT S
:BEGIN))))
on
```

```
   (SPEC-H (AT S :END)) = 3146950.0
   (SPEC-H (AT S :BEGIN)) = 2791500.0
;;; Finished <P: HB4.143>
```

4.145 An inventor has proposed the insulated device shown with air as the medium. Determine T_3.

```
(add-problem :hb4.145
 :givens '((splitter splt (at s :init) (at s :part1) (at s :part2))
           (substance-of (at s :init) air)
           (nvalue (mass (at s :init)) 3.0 kg/s)
           (nvalue (P (at s :init)) 4 Mpa)
           (nvalue (T (at s :init)) 600 C)
           (nvalue (P (at s :part1)) 0.2 Mpa)
           (nvalue (T (at s :part1)) 6 C)
           (nvalue (mass (at s :part1)) 0.5 kg/s)
           (nvalue (P (at s :part2)) 0.2 Mpa))
 :goal '(find (nvalue (T (at s :part2))))
 :answer '(991.8 K))


;;; Answer-for :HB4.145: 594.0
;;; (NVALUE (T (AT S :PART2)) 594.0)
Found (SPEC-H (AT S :PART1)) = 280127.025
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :PART1)) (* (CP AIR) (T (AT S :PART1))))
on
   (T (AT S :PART1)) = 279.15
   (CP AIR) = 1003.5
Found (SPEC-ENERGY (AT S :PART1)) = 280127.025
using equality
    (:= (SPEC-ENERGY (AT S :PART1)) (SPEC-H (AT S :PART1)))
Found (SPEC-H (AT S :INIT)) = 876206.025
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :INIT)) (* (CP AIR) (T (AT S :INIT))))
on
   (T (AT S :INIT)) = 873.15
   (CP AIR) = 1003.5
Found (SPEC-ENERGY (AT S :INIT)) = 876206.025
using equality
    (:= (SPEC-ENERGY (AT S :INIT)) (SPEC-H (AT S :INIT)))
Found (SPEC-ENERGY-INLET SPLT) = 876206.025
using equality
    (:= (SPEC-ENERGY-INLET SPLT) (SPEC-ENERGY (AT S :INIT)))
Found (SPEC-ENERGY-OUTLET SPLT) = 876206.025
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q SPLT) (SPEC-ENERGY-BEGIN SPLT) (SPEC-ENERGY-INLET
SPLT)) (+ (SPEC-ENERGY-END SPLT) (SPEC-ENERGY-OUTLET SPLT) (SPEC-WORK
SPLT)))
on
   (SPEC-ENERGY-END SPLT) = 0
   (SPEC-ENERGY-BEGIN SPLT) = 0
```

```
   (SPEC-Q SPLT) = 0
   (SPEC-WORK SPLT) = 0
   (SPEC-ENERGY-INLET SPLT) = 876206.025
Found (SPEC-ENERGY (AT S :PART2)) = 596079.0
using
    BASIC-PROCESS-ENERGY-OUTLET
    (:= (SPEC-ENERGY-OUTLET SPLT) (+ (SPEC-ENERGY (AT S :PART1))
(SPEC-ENERGY (AT S :PART2))))
on
   (SPEC-ENERGY-OUTLET SPLT) = 876206.025
   (SPEC-ENERGY (AT S :PART1)) = 280127.025
Found (SPEC-H (AT S :PART2)) = 596079.0
using equality
    (:= (SPEC-ENERGY (AT S :PART2)) (SPEC-H (AT S :PART2)))
Found (T (AT S :PART2)) = 594.0
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :PART2)) (* (CP AIR) (T (AT S :PART2))))
on
   (CP AIR) = 1003.5
   (SPEC-H (AT S :PART2)) = 596079.0
;;; Finished <P: HB4.145>
```

4.147 Determine the total rate of change of enthalpy from the inlets to the exit of the isobaric device shown.

```
(add-problem :hb4.147
 :givens '((mixer mix (at s :part1) (at s :part2) (at s :out))
           (substance-of (at s :part1) air)
           (isobaric mix)
           (:not (adiabatic mix))
           (nvalue (mass (at s :part1)) 6 kg/s)
           (nvalue (T (at s :part1)) 20 C)
           (nvalue (P (at s :part1)) 200 kPa)
           (NVALUE (CP AIR) 1005.2)
           (nvalue (mass (at s :part2)) 4 kg/s)
           (nvalue (T (at s :part2)) 300 C)
           (nvalue (T (at s :out)) 150 C)))
  ;; :goal '(find (nvalue (mass (at s :out))))
  :goal '(find (nvalue (delta-h mix)))
  :answer '(180.9 kW))


;;; Answer-for :HB4.147: 180936.0
;;; Answer is correct! Given (180.9 KW) =~ 180.936
;;; (NVALUE (DELTA-H MIX) 180936.0)
Found (SPEC-H (AT S :PART2)) = 576130.38
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :PART2)) (* (CP AIR) (T (AT S :PART2))))
on
   (CP AIR) = 1005.2
   (T (AT S :PART2)) = 573.15
Found (H (AT S :PART2)) = 2304521.52
```

```
using
    SPEC-H-DEFINITION
    (:= (SPEC-H (AT S :PART2)) (/ (H (AT S :PART2)) (MASS (AT S
:PART2))))
on
   (MASS (AT S :PART2)) = 4
   (SPEC-H (AT S :PART2)) = 576130.38
Found (SPEC-H (AT S :PART1)) = 294674.38
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :PART1)) (* (CP AIR) (T (AT S :PART1))))
on
   (T (AT S :PART1)) = 293.15
   (CP AIR) = 1005.2
Found (H (AT S :PART1)) = 1768046.28
using
    SPEC-H-DEFINITION
    (:= (SPEC-H (AT S :PART1)) (/ (H (AT S :PART1)) (MASS (AT S
:PART1))))
on
   (MASS (AT S :PART1)) = 6
   (SPEC-H (AT S :PART1)) = 294674.38
Found (MASS-INLET MIX) = 10
using
    BASIC-PROCESS-ENERGY-INLET
    (:= (MASS-INLET MIX) (+ (MASS (AT S :PART1)) (MASS (AT S
:PART2))))
on
   (MASS (AT S :PART1)) = 6
   (MASS (AT S :PART2)) = 4
Found (MASS-OUTLET MIX) = 10
using
    CONSERVATION-OF-MASS
    (:= (+ (MASS-BEGIN MIX) (MASS-INLET MIX)) (+ (MASS-END MIX)
(MASS-OUTLET MIX)))
on
   (MASS-END MIX) = 0
   (MASS-BEGIN MIX) = 0
   (MASS-INLET MIX) = 10
Found (MASS (AT S :OUT)) = 10
using equality
    (:= (MASS-OUTLET MIX) (MASS (AT S :OUT)))
Found (SPEC-H (AT S :OUT)) = 425350.38
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :OUT)) (* (CP AIR) (T (AT S :OUT))))
on
   (CP AIR) = 1005.2
   (T (AT S :OUT)) = 423.15
Found (H (AT S :OUT)) = 4253503.8
using
    SPEC-H-DEFINITION
    (:= (SPEC-H (AT S :OUT)) (/ (H (AT S :OUT)) (MASS (AT S :OUT))))
on
   (SPEC-H (AT S :OUT)) = 425350.38
   (MASS (AT S :OUT)) = 10
```

```
Found (DELTA-H MIX) = 180936.0
using
    DELTA-H
    (:= (DELTA-H MIX) (- (H (AT S :OUT)) (+ (H (AT S :PART1)) (H (AT
S :PART2)))))
on
   (H (AT S :OUT)) = 4253503.8
   (H (AT S :PART1)) = 1768046.28
   (H (AT S :PART2)) = 2304521.52
;;; Finished <P: HB4.147>
```

4.149 Find the rate of change of enthalpy from the inlet to the exits of the CO_2 device shown.

```
(add-problem :hb4.149
 :givens '((splitter splt (at s :init) (at s :part1) (at s :part2))
           (substance-of (at s :init) Co2)
           (nvalue (mass (at s :init)) 0.4 kg/s)
           (nvalue (P (at s :init)) 150 kPa)
           (nvalue (T (at s :init)) 200 C)
           (nvalue (P (at s :part1)) 100 kPa)
           (nvalue (T (at s :part1)) 200 C)
           (nvalue (mass (at s :part1)) 0.1 kg/s)
           (nvalue (P (at s :part2)) 50 kPa)
           (nvalue (T (at s :part2)) 100 C)
           (nvalue (mass (at s :part2)) 0.3 kg/s))
  :goal '(find (nvalue (delta-h splt)))
  :answer '(-25.39 kW))

;;; Answer-for :HB4.149: -25254.0
;;; Answer is correct! Given (-25.39 KW) =~ -25.254
;;; (NVALUE (DELTA-H SPLT) -25254.0)
Found (SPEC-H (AT S :INIT)) = 398297.67
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :INIT)) (* (CP CO2) (T (AT S :INIT))))
on
   (T (AT S :INIT)) = 473.15
   (CP CO2) = 841.8
Found (H (AT S :INIT)) = 159319.068
using
    SPEC-H-DEFINITION
    (:= (SPEC-H (AT S :INIT)) (/ (H (AT S :INIT)) (MASS (AT S
:INIT))))
on
   (MASS (AT S :INIT)) = 0.4
   (SPEC-H (AT S :INIT)) = 398297.67
Found (SPEC-H (AT S :PART2)) = 314117.67
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :PART2)) (* (CP CO2) (T (AT S :PART2))))
on
   (T (AT S :PART2)) = 373.15
   (CP CO2) = 841.8
```

```
Found (H (AT S :PART2)) = 94235.301
using
    SPEC-H-DEFINITION
    (:= (SPEC-H (AT S :PART2)) (/ (H (AT S :PART2)) (MASS (AT S
:PART2))))
on
   (MASS (AT S :PART2)) = 0.3
   (SPEC-H (AT S :PART2)) = 314117.67
Found (SPEC-H (AT S :PART1)) = 398297.67
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :PART1)) (* (CP CO2) (T (AT S :PART1))))
on
   (T (AT S :PART1)) = 473.15
   (CP CO2) = 841.8
Found (H (AT S :PART1)) = 39829.767
using
    SPEC-H-DEFINITION
    (:= (SPEC-H (AT S :PART1)) (/ (H (AT S :PART1)) (MASS (AT S
:PART1))))
on
   (MASS (AT S :PART1)) = 0.1
   (SPEC-H (AT S :PART1)) = 398297.67
Found (DELTA-H SPLT) = -25254.0
using
    DELTA-H
    (:= (DELTA-H SPLT) (- (+ (H (AT S :PART1)) (H (AT S :PART2))) (H
(AT S :INIT))))
on
   (H (AT S :PART1)) = 39829.767
   (H (AT S :PART2)) = 94235.301
   (H (AT S :INIT)) = 159319.068
;;; Finished <P: HB4.149>
```

4.151 Determine the mass flow rate and temperature of the air at the exit of the adiabatic device shown.

```
(add-problem-description :hb4.151
 :givens '((mixer mix (at s :part1) (at s :part2) (at s :out))
           (substance-of (at s :part1) air)
           (ke-thermodynamic-stuff (at s :part1))
           (ke-thermodynamic-stuff (at s :out))
           (nvalue (mass (at s :part1)) 10 kg/s)
           (nvalue (P (at s :part1)) 400 kPa)
           (nvalue (T (at s :part1)) 200 C)
           (nvalue (velocity (at s :part1)) 150 m/s)
           (nvalue (P (at s :part2)) 400 kPa)
           (nvalue (T (at s :part2)) 400 C)
           (nvalue (mass (at s :part2)) 2 kg/s)
           (nvalue (P (at s :out)) 100 kPa)
           (nvalue (velocity (at s :out)) 300 m/s)))

(add-problem-goal :hb4.151a
  :description :hb4.151
```

```
  :goal '(find (nvalue (mass (at s :out))))
  :answer '(12 kg/s))

(add-problem-goal :hb4.151b
  :description :hb4.151
  :goal '(find (nvalue (T (at s :out))))
  :answer '(197.9 C))


;;; Answer-for :HB4.151A: 12
;;; Answer is correct! Given (12 KG/S) =~ 12
;;; (NVALUE (MASS (AT S :OUT)) 12)
Found (MASS-INLET MIX) = 12
using
    BASIC-PROCESS-ENERGY-INLET
    (:= (MASS-INLET MIX) (+ (MASS (AT S :PART1)) (MASS (AT S
:PART2))))
on
   (MASS (AT S :PART1)) = 10
   (MASS (AT S :PART2)) = 2
Found (MASS-OUTLET MIX) = 12
using
    CONSERVATION-OF-MASS
    (:= (+ (MASS-BEGIN MIX) (MASS-INLET MIX)) (+ (MASS-END MIX)
(MASS-OUTLET MIX)))
on
   (MASS-END MIX) = 0
   (MASS-BEGIN MIX) = 0
   (MASS-INLET MIX) = 12
Found (MASS (AT S :OUT)) = 12
using equality
    (:= (MASS-OUTLET MIX) (MASS (AT S :OUT)))
;;; Finished <P: HB4.151A>


;;; Answer-for :HB4.151B: 1112.66771300448
;;; (NVALUE (T (AT S :OUT)) 1112.66771300448)
Found (SPEC-H (AT S :PART2)) = 675506.025
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :PART2)) (* (CP AIR) (T (AT S :PART2))))
on
   (T (AT S :PART2)) = 673.15
   (CP AIR) = 1003.5
Found (SPEC-ENERGY (AT S :PART2)) = 675506.025
using equality
    (:= (SPEC-ENERGY (AT S :PART2)) (SPEC-H (AT S :PART2)))
Found (SPEC-H (AT S :PART1)) = 474806.025
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :PART1)) (* (CP AIR) (T (AT S :PART1))))
on
   (T (AT S :PART1)) = 473.15
   (CP AIR) = 1003.5
Found (SPEC-ENERGY (AT S :PART1)) = 486056.025
using
```

```
    SS-THERMODYNAMIC-STUFF
    (:= (SPEC-ENERGY (AT S :PART1)) (+ (/ (SQR (VELOCITY (AT S
:PART1))) 2) (SPEC-H (AT S :PART1))))
on
   (VELOCITY (AT S :PART1)) = 150
   (SPEC-H (AT S :PART1)) = 474806.025
Found (SPEC-ENERGY-INLET MIX) = 1161562.05
using
    BASIC-PROCESS-ENERGY-INLET
    (:= (SPEC-ENERGY-INLET MIX) (+ (SPEC-ENERGY (AT S :PART1)) (SPEC-
ENERGY (AT S :PART2))))
on
   (SPEC-ENERGY (AT S :PART1)) = 486056.025
   (SPEC-ENERGY (AT S :PART2)) = 675506.025
Found (SPEC-ENERGY-OUTLET MIX) = 1161562.05
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q MIX) (SPEC-ENERGY-BEGIN MIX) (SPEC-ENERGY-INLET
MIX)) (+ (SPEC-ENERGY-END MIX) (SPEC-ENERGY-OUTLET MIX) (SPEC-WORK
MIX)))
on
   (SPEC-ENERGY-END MIX) = 0
   (SPEC-ENERGY-BEGIN MIX) = 0
   (SPEC-Q MIX) = 0
   (SPEC-WORK MIX) = 0
   (SPEC-ENERGY-INLET MIX) = 1161562.05
Found (SPEC-ENERGY (AT S :OUT)) = 1161562.05
using equality
    (:= (SPEC-ENERGY-OUTLET MIX) (SPEC-ENERGY (AT S :OUT)))
Found (SPEC-H (AT S :OUT)) = 1116562.05
using
    SS-THERMODYNAMIC-STUFF
    (:= (SPEC-ENERGY (AT S :OUT)) (+ (/ (SQR (VELOCITY (AT S :OUT)))
2) (SPEC-H (AT S :OUT))))
on
   (VELOCITY (AT S :OUT)) = 300
   (SPEC-ENERGY (AT S :OUT)) = 1161562.05
Found (T (AT S :OUT)) = 1112.66771300448
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :OUT)) (* (CP AIR) (T (AT S :OUT))))
on
   (CP AIR) = 1003.5
   (SPEC-H (AT S :OUT)) = 1116562.05
;;; Finished <P: HB4.151B>
```

4.153 Find the heat transfer to or from the following device. (*Hint*: The inlet velocity is *not* zero.) The medium is air.

```
(add-problem :hb4.153
 :givens '((splitter splt (at s :init) (at s :part1) (at s :part2))
           (ke-thermodynamic-stuff (at s :init))
           (:not (adiabatic splt))
           (substance-of (at s :init) air)
```

```
           (nvalue (mass (at s :init)) 7.0 kg/s)
           (nvalue (P (at s :init)) 500 kPa)
           (nvalue (T (at s :init)) 100 C)
           (nvalue (x-area (at s :init)) 0.01 m^2)
           (nvalue (P (at s :part1)) 101.3 kPa)
           (nvalue (T (at s :part1)) 150 C)
           (nvalue (mass (at s :part1)) 5.0 kg/s)
           (nvalue (P (at s :part2)) 101.3 kPa)
           (nvalue (T (at s :part2)) 0 C))
 :goal '(find (nvalue (q splt)))
 :answer '(-28.39 kW))


;;; Answer-for :HB4.153: -28503.269841461
;;; Answer is correct! Given (-28.39 KW) =~ -28.503269841461
;;; (NVALUE (Q SPLT) -28503.269841461)
Found (MASS-INLET SPLT) = 7.0
using equality
    (:= (MASS-INLET SPLT) (MASS (AT S :INIT)))
Found (MASS-OUTLET SPLT) = 7.0
using
    CONSERVATION-OF-MASS
    (:= (+ (MASS-BEGIN SPLT) (MASS-INLET SPLT)) (+ (MASS-END SPLT)
(MASS-OUTLET SPLT)))
on
   (MASS-END SPLT) = 0
   (MASS-BEGIN SPLT) = 0
   (MASS-INLET SPLT) = 7.0
Found (MASS (AT S :PART2)) = 2.0
using
    BASIC-PROCESS-ENERGY-OUTLET
    (:= (MASS-OUTLET SPLT) (+ (MASS (AT S :PART1)) (MASS (AT S
:PART2))))
on
   (MASS (AT S :PART1)) = 5.0
   (MASS-OUTLET SPLT) = 7.0
Found (SPEC-H (AT S :PART2)) = 274106.025
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :PART2)) (* (CP AIR) (T (AT S :PART2))))
on
   (T (AT S :PART2)) = 273.15
   (CP AIR) = 1003.5
Found (H (AT S :PART2)) = 548212.05
using
    SPEC-H-DEFINITION
    (:= (SPEC-H (AT S :PART2)) (/ (H (AT S :PART2)) (MASS (AT S
:PART2))))
on
   (SPEC-H (AT S :PART2)) = 274106.025
   (MASS (AT S :PART2)) = 2.0
Found (ENERGY (AT S :PART2)) = 548212.05
using equality
    (:= (ENERGY (AT S :PART2)) (H (AT S :PART2)))
Found (SPEC-H (AT S :PART1)) = 424631.025
using
```

```
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :PART1)) (* (CP AIR) (T (AT S :PART1))))
on
   (T (AT S :PART1)) = 423.15
   (CP AIR) = 1003.5
Found (H (AT S :PART1)) = 2123155.125
using
    SPEC-H-DEFINITION
    (:= (SPEC-H (AT S :PART1)) (/ (H (AT S :PART1)) (MASS (AT S
:PART1))))
on
   (MASS (AT S :PART1)) = 5.0
   (SPEC-H (AT S :PART1)) = 424631.025
Found (ENERGY (AT S :PART1)) = 2123155.125
using equality
    (:= (ENERGY (AT S :PART1)) (H (AT S :PART1)))
Found (ENERGY-OUTLET SPLT) = 2671367.175
using
    BASIC-PROCESS-ENERGY-OUTLET
    (:= (ENERGY-OUTLET SPLT) (+ (ENERGY (AT S :PART1)) (ENERGY (AT S
:PART2))))
on
   (ENERGY (AT S :PART1)) = 2123155.125
   (ENERGY (AT S :PART2)) = 548212.05
Found (SPEC-V (AT S :INIT)) = 0.2141881
using
    IDEAL-GAS-SPEC-VOLUME
    (:= (* (P (AT S :INIT)) (SPEC-V (AT S :INIT))) (* (R AIR) (T (AT
S :INIT))))
on
   (P (AT S :INIT)) = 500000
   (T (AT S :INIT)) = 373.15
   (R AIR) = 287
Found (VELOCITY (AT S :INIT)) = 149.93167
using
    FLOW-VELOCITY-DEFINITION
    (:= (VELOCITY (AT S :INIT)) (/ (* (MASS (AT S :INIT)) (SPEC-V (AT
S :INIT))) (X-AREA (AT S :INIT))))
on
   (MASS (AT S :INIT)) = 7.0
   (X-AREA (AT S :INIT)) = 0.01
   (SPEC-V (AT S :INIT)) = 0.2141881
Found (KINETIC-ENERGY (AT S :INIT)) = 78678.2698414611
using
    KE-DEFINITION
    (:= (KINETIC-ENERGY (AT S :INIT)) (/ (* (MASS (AT S :INIT)) (SQR
(VELOCITY (AT S :INIT)))) 2))
on
   (MASS (AT S :INIT)) = 7.0
   (VELOCITY (AT S :INIT)) = 149.93167
Found (SPEC-H (AT S :INIT)) = 374456.025
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :INIT)) (* (CP AIR) (T (AT S :INIT))))
on
   (T (AT S :INIT)) = 373.15
```

```
   (CP AIR) = 1003.5
Found (H (AT S :INIT)) = 2621192.175
using
    SPEC-H-DEFINITION
    (:= (SPEC-H (AT S :INIT)) (/ (H (AT S :INIT)) (MASS (AT S
:INIT))))
on
   (MASS (AT S :INIT)) = 7.0
   (SPEC-H (AT S :INIT)) = 374456.025
Found (ENERGY (AT S :INIT)) = 2699870.44484146
using
    SS-THERMODYNAMIC-STUFF
    (:= (ENERGY (AT S :INIT)) (+ (H (AT S :INIT)) (KINETIC-ENERGY (AT
S :INIT))))
on
   (H (AT S :INIT)) = 2621192.175
   (KINETIC-ENERGY (AT S :INIT)) = 78678.2698414611
Found (ENERGY-INLET SPLT) = 2699870.44484146
using equality
    (:= (ENERGY-INLET SPLT) (ENERGY (AT S :INIT)))
Found (Q SPLT) = -28503.269841461
using
    CONSERVATION-OF-ENERGY
    (:= (+ (Q SPLT) (ENERGY-BEGIN SPLT) (ENERGY-INLET SPLT)) (+
(ENERGY-END SPLT) (ENERGY-OUTLET SPLT) (WORK SPLT)))
on
   (ENERGY-END SPLT) = 0
   (ENERGY-BEGIN SPLT) = 0
   (WORK SPLT) = 0
   (ENERGY-INLET SPLT) = 2699870.44484146
   (ENERGY-OUTLET SPLT) = 2671367.175
;;; Finished <P: HB4.153>
```

4.157 Helium flows through the steady-state steady flow device shown in Fig. P4.157. Determine the rate of heat transfer (kW).

```
(add-problem :hb4.157
 :givens '((cycle-process dev (at s :in) (at s :out))
           (substance-of (at s :in) helium)
           (nvalue (mass (at s :in)) 10.0 kg/s)
           (nvalue (P (at s :in)) 100 kPa)
           (nvalue (T (at s :in)) 10 C)
           (= (P (at s :in)) (P (at s :out)))
           (nvalue (T (at s :out)) 200 C)
           (nvalue (work dev) -150 kW))
 :goal '(find (nvalue (q dev)))
 :answer '(9716 kW))

;;; Answer-for :HB4.157: 9715940.0
;;; Answer is correct! Given (9716 KW) =~ 9715.94
;;; (NVALUE (Q DEV) 9715940.0)
Found (MASS-INLET DEV) = 10.0
using equality
    (:= (MASS-INLET DEV) (MASS (AT S :IN)))
```

```
Found (MASS-OUTLET DEV) = 10.0
using
    CONSERVATION-OF-MASS
    (:= (+ (MASS-BEGIN DEV) (MASS-INLET DEV)) (+ (MASS-END DEV)
(MASS-OUTLET DEV)))
on
   (MASS-END DEV) = 0
   (MASS-BEGIN DEV) = 0
   (MASS-INLET DEV) = 10.0
Found (MASS (AT S :OUT)) = 10.0
using equality
    (:= (MASS-OUTLET DEV) (MASS (AT S :OUT)))
Found (SPEC-H (AT S :OUT)) = 2456878.69
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :OUT)) (* (CP HELIUM) (T (AT S :OUT))))
on
   (T (AT S :OUT)) = 473.15
   (CP HELIUM) = 5192.6
Found (H (AT S :OUT)) = 2.45687869E7
using
    SPEC-H-DEFINITION
    (:= (SPEC-H (AT S :OUT)) (/ (H (AT S :OUT)) (MASS (AT S :OUT))))
on
   (SPEC-H (AT S :OUT)) = 2456878.69
   (MASS (AT S :OUT)) = 10.0
Found (ENERGY (AT S :OUT)) = 2.45687869E7
using equality
    (:= (ENERGY (AT S :OUT)) (H (AT S :OUT)))
Found (ENERGY-OUTLET DEV) = 2.45687869E7
using equality
    (:= (ENERGY-OUTLET DEV) (ENERGY (AT S :OUT)))
Found (SPEC-H (AT S :IN)) = 1470284.69
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :IN)) (* (CP HELIUM) (T (AT S :IN))))
on
   (T (AT S :IN)) = 283.15
   (CP HELIUM) = 5192.6
Found (H (AT S :IN)) = 1.47028469E7
using
    SPEC-H-DEFINITION
    (:= (SPEC-H (AT S :IN)) (/ (H (AT S :IN)) (MASS (AT S :IN))))
on
   (MASS (AT S :IN)) = 10.0
   (SPEC-H (AT S :IN)) = 1470284.69
Found (ENERGY (AT S :IN)) = 1.47028469E7
using equality
    (:= (ENERGY (AT S :IN)) (H (AT S :IN)))
Found (ENERGY-INLET DEV) = 1.47028469E7
using equality
    (:= (ENERGY-INLET DEV) (ENERGY (AT S :IN)))
Found (Q DEV) = 9715940.0
using
    CONSERVATION-OF-ENERGY
```

```
    (:= (+ (Q DEV) (ENERGY-BEGIN DEV) (ENERGY-INLET DEV)) (+ (ENERGY-
END DEV) (ENERGY-OUTLET DEV) (WORK DEV)))
on
   (WORK DEV) = -150000
   (ENERGY-END DEV) = 0
   (ENERGY-BEGIN DEV) = 0
   (ENERGY-INLET DEV) = 1.47028469E7
   (ENERGY-OUTLET DEV) = 2.45687869E7
;;; Finished <P: HB4.157>
```

4.159 Steam (H_2O) enters and exits the nozzle as shown. Find the exit velocity in meters per second.

```
(add-problem :hb4.159
 :givens '((cycle-process nozzle (at s :in) (at s :out))
           (:not (work-device nozzle))
           (ke-thermodynamic-stuff (at s :in))
           (ke-thermodynamic-stuff (at s :out))
           (substance-of (at s :in) water)
           (nvalue (spec-q nozzle) -120 kj/kg)
           (nvalue (P (at s :in)) 1 Mpa)
           (nvalue (T (at s :in)) 300 C)
           (nvalue (velocity (at s :in)) 75)
           (nvalue (P (at s :out)) 0.08 Mpa)
           (nvalue (T (at s :out)) 200 C))
 :goal '(find (nvalue (velocity (at s :out))))
 :answer '(339.4 m/s))


;;; Answer-for :HB4.159: 339.565899347976
;;; Answer is correct! Given (339.4 M/S) =~ 339.565899347976
;;; (NVALUE (VELOCITY (AT S :OUT)) 339.565899347976)
Found (SPEC-H (AT S :IN)) = 3050600.0
using
    SUPERHEATED-P-T
on
   (P (AT S :IN)) = 1000000
   (T (AT S :IN)) = 573.15
Found (SPEC-ENERGY (AT S :IN)) = 3053412.5
using
    SS-THERMODYNAMIC-STUFF
    (:= (SPEC-ENERGY (AT S :IN)) (+ (/ (SQR (VELOCITY (AT S :IN))) 2)
(SPEC-H (AT S :IN))))
on
   (VELOCITY (AT S :IN)) = 75
   (SPEC-H (AT S :IN)) = 3050600.0
Found (SPEC-ENERGY-INLET NOZZLE) = 3053412.5
using equality
    (:= (SPEC-ENERGY-INLET NOZZLE) (SPEC-ENERGY (AT S :IN)))
Found (SPEC-ENERGY-OUTLET NOZZLE) = 2933412.5
using
    SPEC-CONSERVATION-OF-ENERGY
```

```
    (:= (+ (SPEC-Q NOZZLE) (SPEC-ENERGY-BEGIN NOZZLE) (SPEC-ENERGY-
INLET NOZZLE)) (+ (SPEC-ENERGY-END NOZZLE) (SPEC-ENERGY-OUTLET
NOZZLE) (SPEC-WORK NOZZLE)))
on
   (SPEC-WORK NOZZLE) = 0
   (SPEC-Q NOZZLE) = -120000
   (SPEC-ENERGY-END NOZZLE) = 0
   (SPEC-ENERGY-BEGIN NOZZLE) = 0
   (SPEC-ENERGY-INLET NOZZLE) = 3053412.5
Found (SPEC-ENERGY (AT S :OUT)) = 2933412.5
using equality
    (:= (SPEC-ENERGY-OUTLET NOZZLE) (SPEC-ENERGY (AT S :OUT)))
Found (SPEC-H (AT S :OUT)) = 2875760.0
using
    SUPERHEATED-P-T
on
   (P (AT S :OUT)) = 80000.0
   (T (AT S :OUT)) = 473.15
Found (VELOCITY (AT S :OUT)) = 339.565899347976
using
    SS-THERMODYNAMIC-STUFF
    (:= (SPEC-ENERGY (AT S :OUT)) (+ (/ (SQR (VELOCITY (AT S :OUT)))
2) (SPEC-H (AT S :OUT))))
on
   (SPEC-H (AT S :OUT)) = 2875760.0
   (SPEC-ENERGY (AT S :OUT)) = 2933412.5
;;; Finished <P: HB4.159>
```

4.161 Steam expands through the adiabatic steady-state steady flow nozzle shown. For the given conditions, find the exit velocity V_2.

```
(add-problem :hb4.161
 :givens '((cycle-process nozzle (at s :in) (at s :out))
           (adiabatic nozzle)
           (:not (work-device nozzle))
           (ke-thermodynamic-stuff (at s :in))
           (ke-thermodynamic-stuff (at s :out))
           (substance-of (at s :in) water)
           (adiabatic nozzle)
           (nvalue (P (at s :in)) 2 Mpa)
           (nvalue (T (at s :in)) 450 C)
           (nvalue (velocity (at s :in)) 0)
           (nvalue (P (at s :out)) 0.15 Mpa)
           (nvalue (T (at s :out)) 150 C))
 :goal '(find (nvalue (velocity (at s :out))))
 :answer '(1082 m/s))


;;; Answer-for :HB4.161: 1081.80404879997
;;; Answer is correct! Given (1082 M/S) =~ 1081.80404879997
;;; (NVALUE (VELOCITY (AT S :OUT)) 1081.80404879997)
Found (SPEC-H (AT S :IN)) = 3357500.0
using
    SUPERHEATED-P-T
```

```
on
   (P (AT S :IN)) = 2000000
   (T (AT S :IN)) = 723.15
Found (SPEC-ENERGY (AT S :IN)) = 3357500.0
using
    SS-THERMODYNAMIC-STUFF
    (:= (SPEC-ENERGY (AT S :IN)) (+ (/ (SQR (VELOCITY (AT S :IN))) 2)
(SPEC-H (AT S :IN))))
on
   (VELOCITY (AT S :IN)) = 0
   (SPEC-H (AT S :IN)) = 3357500.0
Found (SPEC-ENERGY-INLET NOZZLE) = 3357500.0
using equality
    (:= (SPEC-ENERGY-INLET NOZZLE) (SPEC-ENERGY (AT S :IN)))
Found (SPEC-ENERGY-OUTLET NOZZLE) = 3357500.0
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q NOZZLE) (SPEC-ENERGY-BEGIN NOZZLE) (SPEC-ENERGY-
INLET NOZZLE)) (+ (SPEC-ENERGY-END NOZZLE) (SPEC-ENERGY-OUTLET
NOZZLE) (SPEC-WORK NOZZLE)))
on
   (SPEC-Q NOZZLE) = 0
   (SPEC-WORK NOZZLE) = 0
   (SPEC-ENERGY-END NOZZLE) = 0
   (SPEC-ENERGY-BEGIN NOZZLE) = 0
   (SPEC-ENERGY-INLET NOZZLE) = 3357500.0
Found (SPEC-ENERGY (AT S :OUT)) = 3357500.0
using equality
    (:= (SPEC-ENERGY-OUTLET NOZZLE) (SPEC-ENERGY (AT S :OUT)))
Found (SPEC-H (AT S :OUT)) = 2772350.0
using
    SUPERHEATED-P-T
on
   (P (AT S :OUT)) = 150000.0
   (T (AT S :OUT)) = 423.15
Found (VELOCITY (AT S :OUT)) = 1081.80404879997
using
    SS-THERMODYNAMIC-STUFF
    (:= (SPEC-ENERGY (AT S :OUT)) (+ (/ (SQR (VELOCITY (AT S :OUT)))
2) (SPEC-H (AT S :OUT))))
on
   (SPEC-H (AT S :OUT)) = 2772350.0
   (SPEC-ENERGY (AT S :OUT)) = 3357500.0
;;; Finished <P: HB4.161>
```

4.163 An air nozzle operates as shown below. Find the exit velocity (m/s).

```
(add-problem :hb4.163
 :givens '((cycle-process nozzle (at s :in) (at s :out))
           (:not (work-device nozzle))
           (ke-thermodynamic-stuff (at s :in))
           (ke-thermodynamic-stuff (at s :out))
           (substance-of (at s :in) air)
           (nvalue (spec-q nozzle) -125 kj/kg)
           (nvalue (P (at s :in)) 1 Mpa)
```

```
           (nvalue (T (at s :in)) 300 C)
           (nvalue (velocity (at s :in)) 75)
           (nvalue (P (at s :out)) 0.08 Mpa)
           (nvalue (T (at s :out)) 150 C))
 :goal '(find (nvalue (velocity (at s :out))))
 :answer '(239.1 m/s))


;;; Answer-for :HB4.163: 238.065117142349
;;; Answer is correct! Given (239.1 M/S) =~ 238.065117142349
;;; (NVALUE (VELOCITY (AT S :OUT)) 238.065117142349)
Found (SPEC-H (AT S :IN)) = 575156.025
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :IN)) (* (CP AIR) (T (AT S :IN))))
on
   (T (AT S :IN)) = 573.15
   (CP AIR) = 1003.5
Found (SPEC-ENERGY (AT S :IN)) = 577968.525
using
    SS-THERMODYNAMIC-STUFF
    (:= (SPEC-ENERGY (AT S :IN)) (+ (/ (SQR (VELOCITY (AT S :IN))) 2)
(SPEC-H (AT S :IN))))
on
   (VELOCITY (AT S :IN)) = 75
   (SPEC-H (AT S :IN)) = 575156.025
Found (SPEC-ENERGY-INLET NOZZLE) = 577968.525
using equality
    (:= (SPEC-ENERGY-INLET NOZZLE) (SPEC-ENERGY (AT S :IN)))
Found (SPEC-ENERGY-OUTLET NOZZLE) = 452968.525
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q NOZZLE) (SPEC-ENERGY-BEGIN NOZZLE) (SPEC-ENERGY-
INLET NOZZLE)) (+ (SPEC-ENERGY-END NOZZLE) (SPEC-ENERGY-OUTLET
NOZZLE) (SPEC-WORK NOZZLE)))
on
   (SPEC-WORK NOZZLE) = 0
   (SPEC-Q NOZZLE) = -125000
   (SPEC-ENERGY-END NOZZLE) = 0
   (SPEC-ENERGY-BEGIN NOZZLE) = 0
   (SPEC-ENERGY-INLET NOZZLE) = 577968.525
Found (SPEC-ENERGY (AT S :OUT)) = 452968.525
using equality
    (:= (SPEC-ENERGY-OUTLET NOZZLE) (SPEC-ENERGY (AT S :OUT)))
Found (SPEC-H (AT S :OUT)) = 424631.025
using
    IDEAL-GAS-ENTHALPY
    (:= (SPEC-H (AT S :OUT)) (* (CP AIR) (T (AT S :OUT))))
on
   (T (AT S :OUT)) = 423.15
   (CP AIR) = 1003.5
Found (VELOCITY (AT S :OUT)) = 238.065117142349
using
    SS-THERMODYNAMIC-STUFF
    (:= (SPEC-ENERGY (AT S :OUT)) (+ (/ (SQR (VELOCITY (AT S :OUT)))
2) (SPEC-H (AT S :OUT))))
```

```
on
   (SPEC-H (AT S :OUT)) = 424631.025
   (SPEC-ENERGY (AT S :OUT)) = 452968.525
;;; Finished <P: HB4.163>
```

4.165 Determine the exit velocity and exit area of the carbon dioxide nozzle shown below.

```
(add-problem :hb4.165
  :givens '((cycle-process nozzle (at s :in) (at s :out))
            (ke-thermodynamic-stuff (at s :out))
            (:not (work-device nozzle))
            (substance-of (at s :in) water)
            (nvalue (cp water) 846.4)
            (nvalue (P (at s :in)) 0.6 Mpa)
            (nvalue (T (at s :in)) 350 C)
            (nvalue (mass (at s :in)) 5 kg/s)
           (nvalue (P (at s :out)) 0.1013 Mpa)
           (nvalue (T (at s :out)) 200 C)
           (nvalue (spec-q nozzle) -25 kJ/kg))
  :goal '(find (nvalue (Q nozzle)))
  :goal '(find (nvalue (velocity (at s :out))))
  :answer '(451.6 m/s))


;;; Answer-for :HB4.165: -125000
Found (MASS-INLET NOZZLE) = 5
using equality
    (:= (MASS-INLET NOZZLE) (MASS (AT S :IN)))
Found (Q NOZZLE) = -125000
using
    Q-DEFINITION
    (:= (Q NOZZLE) (* (SPEC-Q NOZZLE) (MASS-INLET NOZZLE)))
on
   (SPEC-Q NOZZLE) = -25000
   (MASS-INLET NOZZLE) = 5
;;; Finished <P: HB4.165>
```

4.167 In an air conditioning system, saturated liquid refrigerant 12 at $T = 40^{\circ}$C flows through an expansion valve and reaches a final pressure of 300 kPa. What is the quality of the refrigerant 12 after the expansion?

```
(add-problem :hb4.167
 :givens '((cycle-process valve (at s :in) (at s :out))
           (:not (work-device valve))
           (adiabatic valve)
           (:not (ideal-gas-substance refrigerant-12))
           (substance-of (at s :in) refrigerant-12)
           (saturated-liquid (at s :in))
           (nvalue (T (at s :in)) 40 C)
           (saturated (at s :out))
           (nvalue (P (at s :out)) 300 kPa))
```

```
 :goal '(find (nvalue (dryness (at s :out))))
 :answer '(0.26))

;;; Answer-for :HB4.167: 0.259155839433966
;;; Answer is correct! Given (0.26) =~ 0.259155839433966
;;; (NVALUE (DRYNESS (AT S :OUT)) 0.259155839433966)
Found (SPEC-HG (AT S :OUT)) = 187139.70409234
using
    SATURATED-TABLE-P
on
   (P (AT S :OUT)) = 300000
Found (SPEC-HF (AT S :OUT)) = 35218.814270724
using
    SATURATED-TABLE-P
on
   (P (AT S :OUT)) = 300000
Found (SPEC-HG (AT S :IN)) = 203200.0
using
    SATURATED-TABLE-T
on
   (T (AT S :IN)) = 313.15
Found (SPEC-HF (AT S :IN)) = 74590.0
using
    SATURATED-TABLE-T
on
   (T (AT S :IN)) = 313.15
Found (SPEC-H (AT S :IN)) = 74590.0
using
    H-SATURATED-STUFF
    (:= (SPEC-H (AT S :IN)) (+ (SPEC-HF (AT S :IN)) (* (DRYNESS (AT S
:IN)) (- (SPEC-HG (AT S :IN)) (SPEC-HF (AT S :IN))))))
on
   (DRYNESS (AT S :IN)) = 0
   (SPEC-HF (AT S :IN)) = 74590.0
   (SPEC-HG (AT S :IN)) = 203200.0
Found (SPEC-ENERGY (AT S :IN)) = 74590.0
using equality
    (:= (SPEC-ENERGY (AT S :IN)) (SPEC-H (AT S :IN)))
Found (SPEC-ENERGY-INLET VALVE) = 74590.0
using equality
    (:= (SPEC-ENERGY-INLET VALVE) (SPEC-ENERGY (AT S :IN)))
Found (SPEC-ENERGY-OUTLET VALVE) = 74590.0
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q VALVE) (SPEC-ENERGY-BEGIN VALVE) (SPEC-ENERGY-
INLET VALVE)) (+ (SPEC-ENERGY-END VALVE) (SPEC-ENERGY-OUTLET VALVE)
(SPEC-WORK VALVE)))
on
   (SPEC-WORK VALVE) = 0
   (SPEC-Q VALVE) = 0
   (SPEC-ENERGY-END VALVE) = 0
   (SPEC-ENERGY-BEGIN VALVE) = 0
   (SPEC-ENERGY-INLET VALVE) = 74590.0
Found (SPEC-ENERGY (AT S :OUT)) = 74590.0
using equality
    (:= (SPEC-ENERGY-OUTLET VALVE) (SPEC-ENERGY (AT S :OUT)))
```

```
Found (SPEC-H (AT S :OUT)) = 74590.0
using equality
    (:= (SPEC-ENERGY (AT S :OUT)) (SPEC-H (AT S :OUT)))
Found (DRYNESS (AT S :OUT)) = 0.259155839433966
using
    H-SATURATED-STUFF
    (:= (SPEC-H (AT S :OUT)) (+ (SPEC-HF (AT S :OUT)) (* (DRYNESS (AT
S :OUT)) (- (SPEC-HG (AT S :OUT)) (SPEC-HF (AT S :OUT))))))
on
   (SPEC-H (AT S :OUT)) = 74590.0
   (SPEC-HF (AT S :OUT)) = 35218.814270724
   (SPEC-HG (AT S :OUT)) = 187139.70409234
;;; Finished <P: HB4.167>
```

4.171S A fluid flows through a valve. The inlet conditions are1.0 MPa and 400°C, and the exit pressure is 0.3 MPa. See Fig. P4.171. Evaluate the exit temperature for (*a*) steam and (*b*) air as the fluid.

```
(add-problem-description :hb4.171
 :givens '((cycle-process valve (at s :in) (at s :out))
           (:not (work-device valve))
           (adiabatic valve)
           (nvalue (P (at s :in)) 1.0 MPa)
           (nvalue (T (at s :in)) 400 C)
           (nvalue (P (at s :out)) 0.3 MPa)))

(add-problem-goal :hb4.171a
  :description :hb4.171
 :extras '((substance-of (at s :in) water)
           (gas (at s :in)) (gas (at s :out)))
 :goal '(find (nvalue (T (at s :out))))
 :answer '(395 C))

(add-problem-goal :hb4.171b
  :description :hb4.171
 :extras '((substance-of (at s :in) air))
 :goal '(find (nvalue (T (at s :out))))
 :answer '(400 C))


;;; Answer-for :HB4.171A: 667.813461538462
;;; Answer is correct! Given (395 C) =~ 394.663461538462
;;; (NVALUE (T (AT S :OUT)) 667.813461538462)
Found (SPEC-H (AT S :IN)) = 3263800.0
using
    SUPERHEATED-P-T
on
   (P (AT S :IN)) = 1000000.0
   (T (AT S :IN)) = 673.15
Found (SPEC-ENERGY (AT S :IN)) = 3263800.0
using equality
    (:= (SPEC-ENERGY (AT S :IN)) (SPEC-H (AT S :IN)))
Found (SPEC-ENERGY-INLET VALVE) = 3263800.0
using equality
```

```
    (:= (SPEC-ENERGY-INLET VALVE) (SPEC-ENERGY (AT S :IN)))
Found (SPEC-ENERGY-OUTLET VALVE) = 3263800.0
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q VALVE) (SPEC-ENERGY-BEGIN VALVE) (SPEC-ENERGY-
INLET VALVE)) (+ (SPEC-ENERGY-END VALVE) (SPEC-ENERGY-OUTLET VALVE)
(SPEC-WORK VALVE)))
on
   (SPEC-WORK VALVE) = 0
   (SPEC-Q VALVE) = 0
   (SPEC-ENERGY-END VALVE) = 0
   (SPEC-ENERGY-BEGIN VALVE) = 0
   (SPEC-ENERGY-INLET VALVE) = 3263800.0
Found (SPEC-ENERGY (AT S :OUT)) = 3263800.0
using equality
    (:= (SPEC-ENERGY-OUTLET VALVE) (SPEC-ENERGY (AT S :OUT)))
Found (SPEC-H (AT S :OUT)) = 3263800.0
using equality
    (:= (SPEC-ENERGY (AT S :OUT)) (SPEC-H (AT S :OUT)))
Found (T (AT S :OUT)) = 667.813461538462
using
    SUPERHEATED-P-SPEC-H
on
   (P (AT S :OUT)) = 300000.0
   (SPEC-H (AT S :OUT)) = 3263800.0
;;; Finished <P: HB4.171A>


;;; Answer-for :HB4.171B: 673.15
;;; Answer is correct! Given (400 C) =~ 400.0
;;; (NVALUE (T (AT S :OUT)) 673.15)
Found (SPEC-H (AT S :IN)) = 684504.2
using
    IDEAL-T-LOOKUP
on
   (T (AT S :IN)) = 673.15
Found (SPEC-ENERGY (AT S :IN)) = 684504.2
using equality
    (:= (SPEC-ENERGY (AT S :IN)) (SPEC-H (AT S :IN)))
Found (SPEC-ENERGY-INLET VALVE) = 684504.2
using equality
    (:= (SPEC-ENERGY-INLET VALVE) (SPEC-ENERGY (AT S :IN)))
Found (SPEC-ENERGY-OUTLET VALVE) = 684504.2
using
    SPEC-CONSERVATION-OF-ENERGY
    (:= (+ (SPEC-Q VALVE) (SPEC-ENERGY-BEGIN VALVE) (SPEC-ENERGY-
INLET VALVE)) (+ (SPEC-ENERGY-END VALVE) (SPEC-ENERGY-OUTLET VALVE)
(SPEC-WORK VALVE)))
on
   (SPEC-WORK VALVE) = 0
   (SPEC-Q VALVE) = 0
   (SPEC-ENERGY-END VALVE) = 0
   (SPEC-ENERGY-BEGIN VALVE) = 0
   (SPEC-ENERGY-INLET VALVE) = 684504.2
Found (SPEC-ENERGY (AT S :OUT)) = 684504.2
using equality
```

```
    (:= (SPEC-ENERGY-OUTLET VALVE) (SPEC-ENERGY (AT S :OUT)))
Found (SPEC-H (AT S :OUT)) = 684504.2
using equality
    (:= (SPEC-ENERGY (AT S :OUT)) (SPEC-H (AT S :OUT)))
Found (T (AT S :OUT)) = 673.15
using
    IDEAL-SPEC-H-LOOKUP
on
   (SPEC-H (AT S :OUT)) = 684504.2
;;; Finished <P: HB4.171B>
```