

## Heat Pump

### RECORD AND ANALYSE THE PRESSURE-ENTHALPY DIAGRAM FOR A COMPRESSION HEAT PUMP

- Demonstrate how an electric compression heat pump works
- Quantitatively investigate of the related cyclical process
- Record and analyse the pressure-enthalpy diagram for a compression heat pump

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Fig. 1: Experiment set-up

### GENERAL PRINCIPLES

An electric compression heat pump consists of a compressor with a drive motor, a condenser, an expansion valve and an evaporator. Its operation is based on a cyclical process a phase transition, which the working medium inside the pump undergoes. Ideally, this process can be

divided into four steps, comprising compression, liquefaction, depressurisation and evaporation.

For the compression part of the cycle, the gaseous working medium is drawn in by the compressor and compressed without any change in entropy ( $s_1 = s_2$ ) from  $p_1$  to  $p_2$ , during which process the medium heats up (see Figs. 2 and 3). The temperature accordingly rises from  $T_1$  to  $T_2$ . The mechanical compression work performed per unit of mass is  $\Delta w = h_2 - h_1$ .

Inside the condenser, the working medium cools considerably and condenses. The heat released as a result (excess heat and latent heat of condensation) per unit of mass is  $\Delta q^{cond} = h_2 - h_3$ . It raises the temperature of the surrounding reservoir.

The condensed working medium reaches the release valve, where it is depressurised (without doing any mechanical work). In this process, the temperature also decreases due to the work which needs to be performed in opposition to the molecular forces of attraction inside the working medium (Joule-Thomson effect). The enthalpy remains constant ( $h_4 = h_3$ ).

As it absorbs heat inside the evaporator, the working medium evaporates fully. This cools the surrounding reservoir. The heat absorbed per unit of mass is  $\Delta q^{vapo} = h_1 - h_4$ .

A Mollier diagram of the working medium is often used to represent the cycle of a compression heat pump. This diagram plots the pressure  $p$  against the specific enthalpy  $h$  of the working medium (enthalpy is a measure of the working medium's heat content and generally rises with the pressure and gas content).

Also specified are the isotherms ( $T = \text{constant}$ ) and isentropes ( $s = \text{constant}$ ), as well as the relative proportion by mass of the working medium in the liquid phase. The working medium condenses fully to the left of the vaporisation phase boundary line. The medium is present as superheated steam to the right of the condensation phase boundary and as a mixture of liquid and gas between the two lines. The two lines make contact at the critical point.

To depict the system in a Mollier diagram, the ideal cycle described above can be determined by measuring the pressures  $p_4 = p_1$  and  $p_3 = p_2$  respectively before and after the expansion valve, as well as the temperatures  $T_1$  and  $T_3$  respectively before the compressor and expansion valve.

The components in this experiment are connected via a copper pipe to form a closed system, and mounted on a base board. Thanks to the clarity of the set-up, it is easy to associate them with the sequence of phase changes taking place in the heat pump cycle. The evaporator and condenser are designed as coiled copper tubes and they are each immersed in a separate water bath which serves as a reservoir for determining absorbed or emitted heat. Two large manometers indicate the pressures on the refrigerant in the two heat exchangers. Two digital thermometers allow you to measure temperature in the two water baths. Temperature sensors with specially designed measuring terminals are used to register the temperatures in the copper tube before the compressor and the expansion valve.

The performance coefficient for an ideal cyclical process can be calculated from the specific enthalpies  $h_1$ ,  $h_2$  and  $h_3$  read from a Mollier diagram:

$$(1) \quad \varepsilon = \frac{\Delta q^{cond}}{\Delta w} = \frac{(h_2 - h_3)}{(h_2 - h_1)}$$

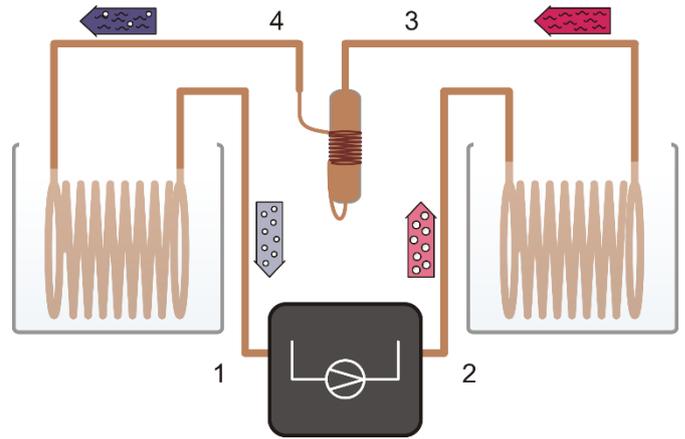


Fig. 2: Schematic representation of the heat pump with a compressor (1, 2), condenser (2, 3), expansion valve (3, 4) and evaporator (4, 1)

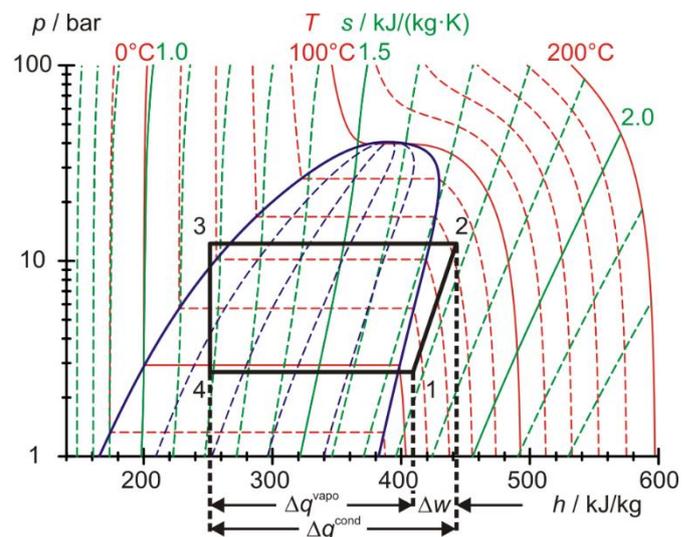


Fig. 3: Representation of ideal cyclical process for heat pump in a Mollier diagram

Determining the enthalpies  $h_2$  and  $h_3$  of the ideal cyclical process and the quantity of heat  $\Delta Q^{cond}$  supplied to the hot water reservoir per time interval  $\Delta t$  makes it possible to estimate the mass flow of the working medium.

$$(2) \quad \frac{\Delta m}{\Delta t} = \frac{\Delta Q^{cond}}{\Delta t} \cdot \frac{1}{(h_2 - h_3)}$$

### LIST OF EQUIPMENT

1	Heat Pump D @230V	1000820 (U8440600-230)
or		
1	Heat Pump D @115V	1000819 (U8440600-115)
4	Temperature Sensor NTC with Measurement Terminal	1021797 (U8558010)
1	VinciLab	1021477 (UCMA-001)
1	Coach 7, University License 5 Years	1021524 (UCMA-185U)

## SET-UP AND OPERATION

### VinciLab and temperature sensors

- Install the Coach 7 software on the computer to be used for measurements.
- Connect VinciLab to the computer with the help of the USB cable.
- Connect one temperature sensor to the copper piping in front of the compressor (measuring point 1 in Fig. 2), connect one behind the compressor (measuring point 2), one before the expansion valve (measuring point 3) and one behind the expansion valve (measuring point 4) and connect them to the analogue inputs A1, A2, A3 and A4 on the VinciLab unit.
- Start VinciLab and Coach 7. Click the  in Coach 7. In the "Log-in" window which opens you should select the user name "Author" from the drop-down menu and enter the password for that user name, confirming it with OK.
- Click . In the "Settings for activities" window which then opens, you should confirm the pre-selections "Type of activity: Measurement" and "Interface: VinciLab" by clicking OK.

The software establishes a connection to VinciLab. An image of VinciLab with pictograms of the connected sensors appears in the bottom left of the four windows.

- Set up a measuring duration of an hour and a measurement frequency of 30 seconds by clicking the  button. Set the measurement duration to 3600 seconds and the frequency to 2 per minute, then confirm these with OK.
- Click the  button.

The data table (still empty) will appear in the top right window. VinciLab und Coach 7 are now configured ready to carry out measurements.

### Heat pump

Safety warning:

	<ul style="list-style-type: none"> <li>• Before putting the heat pump into operation it is essential to read the safety instructions in section 2 of the instruction manual for the pump and comply with them.</li> </ul>
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- Fill both reservoirs with 2000 ml of water and insert them into their metal holders.
- Connect the heat pump to the mains.
- Turn on the compressor it to run for about 10 minutes so that it reaches its operating temperature.
- Replace the water, this time determining the mass of water in each of the reservoirs and making a note of both values.
- Put the temperature probes of the digital thermometers into the water reservoirs.

Note:

The water should be at room temperature (about 20 – 25°C), otherwise the evaporator can freeze up during the measurement so much that the stirrer can no longer move.

## EXPERIMENT PROCEDURE

Note:

Due to the extensive quantity of measurements to be made, it is recommended that this experiment be carried out in pairs.

The water in both reservoirs must continue to be well stirred for the entire duration of the experiment.

- Read off the pressure values from the gauges and the water temperatures from the digital thermometers for the heat pump and make a note of these as initial values.
- Do not yet turn on the compressor for the heat pump. First initiate a measurement in Coach 7 by clicking the  button. An entry reading "0 data rows" will appear in the data window. After the configured measurement frequency of 30 seconds has elapsed, the entry "1 data row" and a button with the symbol "+" will appear. Now turn on the compressor and click the "+" symbol.

Clicking the "+" symbol opens the table and displays the measurements. Initially it will only contain the row for  $t = 0$  s with the initial values for temperatures  $T_1, T_2, T_3$  and  $T_4$ .

- As soon as another 390 seconds has elapsed and the second row has appeared in the table ( $t = 30$  s), read off the pressures from the gauges, the temperatures from the digital thermometers and the compressor power from the energy monitor for the heat pump and write them down.
- Continue measuring in this way until the overheating safety switch for the heat pump triggers and then click the  button to finish the measurement.
- Click the spanner in the title bar of the window with the data table. From the "Measurements" menu which opens, select "Export CSV File" and confirm this with OK. A window will open in which you should enter a name for the file, select a folder and click "Save".

Alternatively you can highlight the measurements in the table (omitting column headings) and use copy and paste to insert them into an Excel® table, for example.

## SAMPLE MEASUREMENT AND EVALUATION

Mass of water in evaporator  $m_{H_2O}^{vapo}$ : 1.98 kg

Mass of water in condenser  $m_{H_2O}^{cond}$ : 1.98 kg

The data measured for the temperatures, pressures and compressor power can be found in an Excel® table in the appendix. The first five columns correspond to the CSV file exported from Coach 7 with the values already sensibly rounded off. The next five columns have been added subsequently and correspond to the manually recorded measurements of water temperature, pressure and compressor power. Pressures  $p_3$  and  $p_4$  have already been converted to absolute pressure figures using the following expression:

$$(3) \quad p_3 = p_{e3} + 1 \text{ bar and } p_4 = p_{e4} + 1 \text{ bar}$$

$p_{e3}, p_{e4}$ : Measured pressure over atmospheric

The values highlighted in grey and shown bold for  $t = 900$  s and  $t = 1020$  s are to be used for the power efficiency calculation.

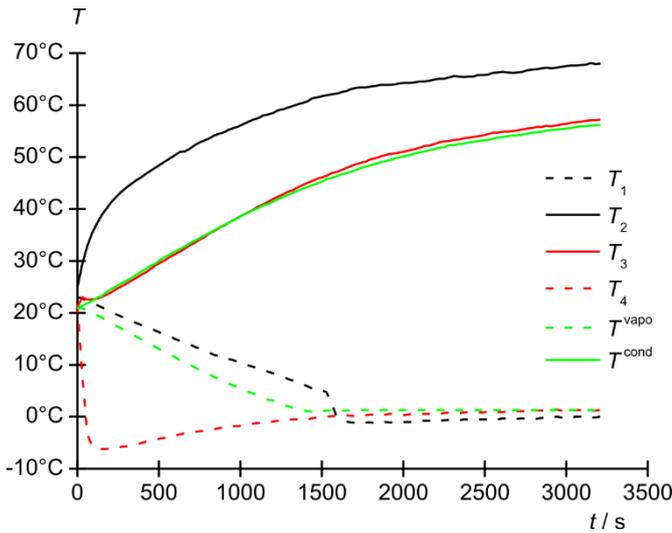


Fig. 4: Changes in temperatures  $T_1$ ,  $T_2$ ,  $T_3$ , and  $T_4$ , over time at measuring points 1 to 4 and  $T^{vapo}$  and  $T^{cond}$  for the cold-water and hot-water reservoirs respectively. Black: compressor, red: expansion valve, green: water reservoirs. Solid lines: hot side, dotted lines: cold side

**Temperature curves**

- Plot the way temperatures  $T_1$ ,  $T_2$ ,  $T_3$ , and  $T_4$  at measuring points 1 to 4 and  $T^{vapo}$  and  $T^{cond}$  for the cold-water and hot-water reservoirs change over time in the form of a graph (Fig. 4).

As expected, temperature  $T_2$  rises due to overheating of the working medium due to compression and temperature  $T_4$  drops sharply due to the constriction. The heat released as a result of the medium cooling in the condenser causes temperature  $T^{cond}$  in the hot-water reservoir to rise. The heat absorbed during complete vaporisation of the working medium causes the cold-water reservoir to cool down and therefore its temperature  $T^{vapo}$  also drops.

Temperatures  $T_1$  and  $T_3$  after evaporation or absorption of heat by the working medium from the cold-water reservoir and after liquefaction or emission of heat from the working medium to the hot-water reservoir are roughly equal to those of the cold-water and hot-water reservoirs  $T^{vapo}$  and  $T^{cond}$  apart from heat losses, primarily to the surroundings. After about 25 minutes (1500 s), the evaporator becomes so frozen up that temperatures  $T_1$ ,  $T_4$  and  $T^{vapo}$  no longer change by any significant amount. This is because the layer of ice on the copper piping coils acts as thermal insulation.

**Heat cycle as Mollier diagram and power efficiency**

- Plot the cyclical process for the heat pump using the values recorded for  $T_1$ ,  $T_2$ ,  $T_3$ ,  $T_4$ ,  $p_3$  and  $p_4$  at  $t = 900$  s in the form of a Mollier diagram (Table 1, Fig 5) and read off the values for the specific enthalpies  $h_1$ ,  $h_2$  and  $h_3 = h_4$ .

$T_1$  and  $p_4 = p_1$  determine point 1 in the Mollier diagram. The intersection where the relevant isentrope crosses the horizontal line  $p_3 = p_2 = \text{constant}$  determines point 2. The intersection of the horizontal with the isotherms  $T_3$  determines point 3, while a perpendicular to the horizontal line  $p_4 = \text{constant}$  determines point 4.

The heat cycle process follows the expected curve. Due to heat losses in the compressor, though, the measurement of the temperature  $T_2$  (54.8°C) does not match the isentropic extrapolation (65.0°C).

The following values for the specific enthalpies can be read from the Mollier diagram:

$$h_1 = 409 \frac{\text{kJ}}{\text{kg}}$$

$$(4) \quad h_2 = 443 \frac{\text{kJ}}{\text{kg}}$$

$$h_3 = 252 \frac{\text{kJ}}{\text{kg}} = h_4$$

**Note:**

The measurement of the temperature  $T_3$  provides an advanced insight into the processes taking place in the heat pump.  $T_3$  does not coincide with the temperature reading on the related manometer's temperature scale. This temperature scale is based on the vapour pressure curve for the working medium. The measurement therefore shows that the working medium before the expansion valve does not comprise a mixture of liquid and gas, but is entirely liquid.

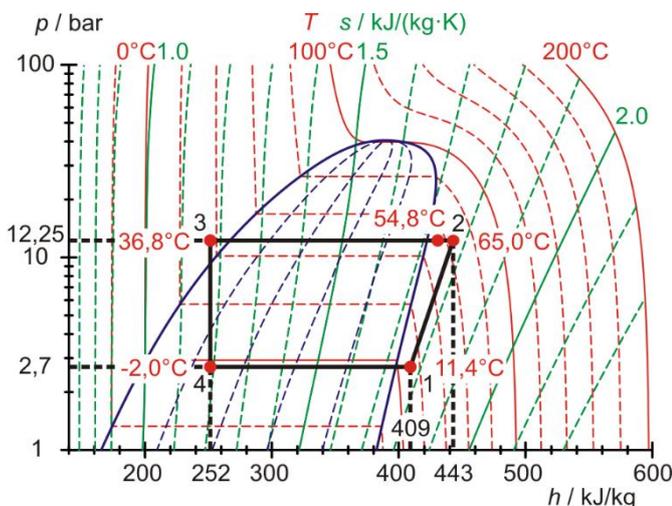


Fig. 5: Display of heat cycle for heat pump as a Mollier diagram, 15 minutes after compressor is switched on

**Coefficient of performance**

According to equation (1), the coefficient of performance in the ideal case would be as follows:

$$(5) \quad \varepsilon = \frac{\Delta q^{\text{cond}}}{\Delta w} = \frac{(h_2 - h_3)}{(h_2 - h_1)} = \frac{(443 - 252) \frac{\text{kJ}}{\text{kg}}}{(443 - 409) \frac{\text{kJ}}{\text{kg}}} = 5.6$$

The coefficient of performance derived from the increase in the heat of the hot-water reservoir comes to:

$$(6) \quad \begin{aligned} \varepsilon &= \frac{\Delta q^{\text{cond}}}{\Delta w} = \frac{\Delta Q^{\text{cond}}}{\Delta W} = \frac{m_{\text{H}_2\text{O}} \cdot c_{\text{H}_2\text{O}} \cdot \Delta T^{\text{cond}}}{P \cdot \Delta t} \\ &= \frac{m_{\text{H}_2\text{O}} \cdot c_{\text{H}_2\text{O}} \cdot (T_{1020 \text{ s}}^{\text{cond}} - T_{900 \text{ s}}^{\text{cond}})}{P \cdot \Delta t} \\ &= \frac{1.98 \text{ kg} \cdot 4.19 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \cdot (38.9 - 36.9)^\circ\text{C}}{116.5 \text{ W} \cdot 120 \text{ s}} = 1.2 \end{aligned}$$

Therefore  $1.2/5.6 = 0.21 = 21\%$  of the electric power is used for compression.

**Mass flow of working medium**

According to equation (2), the following applies:

$$(7) \quad \begin{aligned} \frac{\Delta m}{\Delta t} &= \frac{\Delta Q^{\text{cond}}}{\Delta t} \cdot \frac{1}{(h_2 - h_3)} \\ &= \frac{m_{\text{H}_2\text{O}} \cdot c_{\text{H}_2\text{O}} \cdot \Delta T^{\text{cond}}}{\Delta t} \cdot \frac{1}{(h_2 - h_3)} \\ &= \frac{m_{\text{H}_2\text{O}} \cdot c_{\text{H}_2\text{O}} \cdot (T_{1020 \text{ s}}^{\text{cond}} - T_{900 \text{ s}}^{\text{cond}})}{\Delta t} \cdot \frac{1}{(h_2 - h_3)} \\ &= \frac{1.98 \text{ kg} \cdot 4.19 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \cdot (38.9 - 36.9)^\circ\text{C}}{120 \text{ s} \cdot (443 - 252) \frac{\text{kJ}}{\text{kg}}} \\ &= 0.72 \frac{\text{g}}{\text{s}} \end{aligned}$$

**Effective compressor power**

$$(8) \quad \begin{aligned} P_{\text{eff}} &= \frac{\Delta Q^{\text{comp}}}{\Delta t} = (h_2 - h_1) \cdot \frac{\Delta m}{\Delta t} \\ &= (443 - 409) \frac{\text{kJ}}{\text{kg}} \cdot 0.72 \frac{\text{g}}{\text{s}} = 24.5 \text{ W} \end{aligned}$$

$24.5 \text{ W}/116.5 \text{ W} = 0.21 = 21\%$  of the electric power is used for compression, which matches the figure arrived at by considering the coefficient of performance.

**Power efficiency**

The effective compressor power is derived from the quantity of heat  $\Delta Q^{\text{cond}}$  transferred to the hot-water reservoir in an interval of time  $\Delta t$  minus the quantity of heat taken from the cold-water reservoir  $\Delta Q^{\text{vapo}}$  during the same time interval  $\Delta t$ :

$$(9) \quad \begin{aligned} \frac{\Delta Q^{\text{cond}}}{\Delta t} &= \frac{m_{\text{H}_2\text{O}} \cdot c_{\text{H}_2\text{O}} \cdot \Delta T^{\text{cond}}}{\Delta t} \\ &= \frac{m_{\text{H}_2\text{O}} \cdot c_{\text{H}_2\text{O}} \cdot (T_{1020 \text{ s}}^{\text{cond}} - T_{900 \text{ s}}^{\text{cond}})}{\Delta t} \\ &= \frac{1.98 \text{ kg} \cdot 4.19 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \cdot (38.9 - 36.9)^\circ\text{C}}{120 \text{ s}} \\ &= 138 \text{ W} \end{aligned}$$

$$(10) \quad \begin{aligned} \frac{\Delta Q^{\text{vapo}}}{\Delta t} &= \frac{m_{\text{H}_2\text{O}} \cdot c_{\text{H}_2\text{O}} \cdot \Delta T^{\text{vapo}}}{\Delta t} \\ &= \frac{m_{\text{H}_2\text{O}} \cdot c_{\text{H}_2\text{O}} \cdot (T_{900 \text{ s}}^{\text{vapo}} - T_{1020 \text{ s}}^{\text{vapo}})}{\Delta t} \\ &= \frac{1.98 \text{ kg} \cdot 4.19 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \cdot (6.8 - 5.2)^\circ\text{C}}{120 \text{ s}} \\ &= 111 \text{ W} \end{aligned}$$

Therefore:

$$(11) \quad \begin{aligned} P_{\text{eff}} &= \frac{\Delta Q^{\text{comp}}}{\Delta t} = \frac{\Delta Q^{\text{cond}}}{\Delta t} - \frac{\Delta Q^{\text{vapo}}}{\Delta t} \\ &= 138 \text{ W} - 111 \text{ W} = 27 \text{ W} \end{aligned}$$

This agrees well with the value of 24.5 W as calculated above.

## APPENDIX

Table 1: Temperatures  $T_1$ ,  $T_2$ ,  $T_3$  and  $T_4$  at measuring points 1 to 4 and  $T^{\text{vapo}}$  and  $T^{\text{cond}}$  for the cold-water and hot-water reservoirs, absolute pressures  $p_3$  and  $p_4$  before and after the expansion valve and compressor power  $P$ . The first five columns correspond to the CSV file exported from Coach 7 with the values already sensibly rounded off. The next five columns have been added subsequently and correspond to the manually recorded measurements of water temperature, pressure and compressor power.

Time	T1	T2	T3	T4	Tvapo	Tcond	p3	p4	P
s	°C	°C	°C	°C	°C	°C	bar	bar	W
0	23.0	25.0	21.2	21.5	20.9	20.9	4.75	4.4	0.0
30	22.8	29.5	23.0	7.7	20.9	21.4	8.75	1.9	97.8
60	22.3	32.9	22.6	-3.4	20.5	21.9	8.75	2.0	101.1
90	21.8	35.4	22.6	-5.7	20.1	22.3	9.00	2.1	102.7
120	21.5	37.3	22.7	-6.2	19.5	22.9	9.00	2.2	103.2
150	21.1	38.9	23.1	-6.2	19.1	23.3	9.00	2.2	104.3
180	20.5	40.2	23.5	-6.2	18.5	24.1	9.25	2.2	105.1
210	20.2	41.4	24.0	-6.1	18.0	24.6	9.50	2.3	105.8
240	19.7	42.4	24.6	-6.0	17.5	25.1	9.50	2.3	106.7
270	19.3	43.3	25.1	-5.8	17.0	25.7	9.50	2.3	106.5
300	18.9	44.1	25.6	-5.7	16.4	26.2	9.75	2.3	107.0
330	18.5	44.8	26.2	-5.5	16.0	26.7	9.75	2.4	107.9
360	18.1	45.5	26.7	-5.3	15.4	27.3	10.00	2.4	108.8
390	17.7	46.1	27.3	-5.1	14.9	28.9	10.00	2.4	108.9
420	17.3	46.8	27.8	-4.8	14.4	28.5	10.00	2.4	109.7
450	16.9	47.4	28.5	-4.6	13.9	29.1	10.25	2.5	110.2
480	16.6	48.0	29.2	-4.4	13.4	29.5	10.50	2.5	110.3
510	16.1	48.6	29.7	-4.2	12.9	30.3	10.50	2.5	111.3
540	15.8	49.2	30.2	-4.0	12.5	30.8	10.50	2.5	111.5
570	15.4	49.8	30.8	-3.8	11.9	31.3	10.75	2.5	111.9
600	15.0	50.4	31.3	-3.6	11.5	31.8	11.00	2.6	112.3
630	14.6	51.0	31.8	-3.4	10.9	32.3	11.00	2.6	112.3
660	14.2	51.1	32.4	-3.1	10.6	32.8	11.00	2.6	113.6
690	13.9	51.6	33.0	-3.1	10.0	33.4	11.25	2.6	113.5
720	13.5	52.3	33.5	-2.9	9.5	33.9	11.50	2.6	114.0
750	13.1	52.8	34.1	-2.8	9.0	34.4	11.50	2.6	114.1
780	12.7	53.2	34.6	-2.7	8.5	34.9	11.75	2.6	115.0
810	12.3	53.6	35.3	-2.5	8.1	35.4	12.00	2.6	115.2
840	11.9	54.2	35.8	-2.4	7.7	35.9	12.00	2.7	115.6
870	11.7	54.5	36.4	-2.2	7.2	36.5	12.00	2.7	116.5
<b>900</b>	<b>11.4</b>	<b>54.8</b>	<b>36.8</b>	<b>-2.0</b>	<b>6.8</b>	<b>36.9</b>	<b>12.25</b>	<b>2.7</b>	<b>116.5</b>
930	11.1	55.3	37.4	-2.0	6.4	37.4	12.50	2.7	117.0
960	10.9	55.6	37.9	-1.8	6.0	37.9	12.50	2.7	117.2
990	10.5	55.9	38.4	-1.8	5.6	38.3	12.50	2.7	117.5
<b>1020</b>	<b>10.1</b>	<b>56.4</b>	<b>38.9</b>	<b>-1.6</b>	<b>5.2</b>	<b>38.9</b>	<b>12.75</b>	<b>2.7</b>	<b>118.7</b>
1050	9.9	56.8	39.4	-1.4	4.8	39.3	13.00	2.8	119.2
1080	9.6	57.2	39.9	-1.3	4.5	39.8	13.00	2.8	118.7
1110	9.4	57.5	40.5	-1.2	4.1	40.2	13.00	2.8	119.6
1140	9.1	58.0	40.9	-1.2	3.6	40.7	13.25	2.8	119.6

1170	8.7	58.2	41.4	-1.0	3.3	41.0	13.50	2.8	120.3
1200	8.4	58.5	41.9	-0.9	3.1	41.4	13.50	2.8	120.2
1230	8.1	59.0	42.4	-0.8	2.7	41.9	13.75	2.8	121.1
1260	7.7	59.2	42.8	-0.7	2.3	42.3	13.75	2.8	121.6
1290	7.3	59.5	43.3	-0.6	2.1	42.7	14.00	2.8	121.7
1320	7.0	59.8	43.6	-0.5	1.8	43.1	14.00	2.8	122.1
1350	6.6	60.1	44.1	-0.5	1.5	43.5	14.00	2.8	122.0
1380	6.3	60.4	44.6	-0.3	1.3	43.9	14.25	2.8	122.8
1410	5.9	60.7	45.0	-0.5	1.1	44.2	14.50	2.8	122.6
1440	5.5	61.6	45.4	-0.3	1.0	44.6	14.50	2.8	122.9
1470	5.1	61.5	45.8	-0.1	1.1	44.9	14.50	2.8	123.2
1500	5.1	61.7	46.1	-0.1	1.1	45.3	14.75	2.8	123.6
1530	4.7	61.9	46.4	0.0	1.2	45.8	14.75	2.9	123.7
1560	2.5	62.1	46.9	0.1	1.2	46.0	15.00	2.9	123.8
1590	0.1	62.2	47.1	0.2	1.2	46.3	15.00	2.9	124.5
1620	-0.6	62.5	47.5	0.2	1.2	46.7	15.00	2.9	124.7
1650	-0.9	62.7	47.9	0.3	1.2	46.9	15.25	2.9	124.9
1680	-1.1	63.1	48.3	0.2	1.3	47.2	15.50	2.9	125.0
1710	-1.2	63.3	48.6	0.1	1.3	47.5	15.50	2.9	125.1
1740	-1.1	63.4	48.9	0.2	1.3	47.9	15.50	2.9	125.4
1770	-1.1	63.4	49.1	0.3	1.3	48.2	15.75	2.9	125.9
1800	-1.1	63.6	49.6	0.4	1.3	48.4	15.75	2.9	126.0
1830	-1.2	63.7	49.8	0.4	1.3	48.7	16.00	2.9	126.0
1860	-1.2	63.9	50.1	0.4	1.3	49.0	16.00	2.9	126.4
1890	-1.0	63.9	50.4	0.4	1.3	49.2	16.00	2.9	126.3
1920	-1.1	63.9	50.6	0.6	1.3	49.4	16.00	2.9	126.6
1950	-1.1	64.0	50.7	0.5	1.3	49.8	16.25	2.9	127.0
1980	-1.1	64.2	50.9	0.6	1.3	50.0	16.25	2.9	127.3
2010	-1.0	64.3	51.1	0.3	1.3	50.2	16.50	2.9	127.2
2040	-1.0	64.3	51.3	0.5	1.3	50.4	16.50	2.9	127.3
2070	-0.8	64.4	51.5	0.7	1.3	50.7	16.50	2.9	127.5
2100	-0.7	64.5	51.8	0.6	1.3	50.9	16.50	2.9	127.7
2130	-0.8	64.5	52.1	0.6	1.3	51.1	16.75	2.9	128.0
2160	-0.8	64.7	52.2	0.6	1.3	51.3	16.75	2.9	128.6
2190	-0.8	64.9	52.5	0.6	1.3	51.5	17.00	2.9	128.6
2220	-0.8	65.1	52.8	0.6	1.3	51.8	17.00	3.0	128.8
2250	-0.7	65.1	53.0	0.7	1.3	51.9	17.00	3.0	128.9
2280	-0.6	65.3	53.1	0.8	1.3	52.3	17.00	3.0	128.9
2310	-0.5	65.6	53.3	0.8	1.3	52.3	17.00	3.0	129.0
2340	-0.7	65.5	53.4	0.7	1.3	52.5	17.00	3.0	129.2
2370	-0.5	65.4	53.6	0.8	1.3	52.6	17.50	3.0	129.4
2400	-0.5	65.5	53.7	0.9	1.3	52.8	17.50	3.0	129.8
2430	-0.4	65.5	53.9	0.8	1.3	52.9	17.25	3.0	129.4
2460	-0.5	65.8	54.0	0.8	1.3	53.1	17.50	3.0	129.9
2490	-0.5	65.8	54.2	0.8	1.3	53.2	17.50	3.0	130.0
2520	-0.5	65.9	54.4	1.0	1.3	53.3	17.50	3.0	130.1

2550	-0.5	66.2	54.7	1.0	1.3	53.5	17.50	3.0	130.5
2580	-0.5	66.3	54.7	0.9	1.3	53.7	17.50	3.0	130.1
2610	-0.3	66.4	54.9	0.9	1.3	53.9	17.75	3.0	130.6
2640	-0.4	66.3	54.9	1.0	1.3	54.0	17.75	3.0	130.5
2670	-0.5	66.2	55.0	1.1	1.3	54.2	17.75	3.0	130.8
2700	-0.4	66.3	55.1	1.1	1.3	54.2	18.00	3.0	130.8
2730	-0.3	66.4	55.3	1.1	1.3	54.3	18.00	3.0	130.8
2760	-0.4	66.7	55.5	1.1	1.3	54.5	18.00	3.0	131.5
2790	-0.4	66.8	55.6	1.2	1.3	54.7	18.00	3.0	131.5
2820	-0.4	66.9	55.8	1.2	1.3	54.8	18.00	3.0	130.8
2850	-0.2	67.1	55.8	1.2	1.3	54.9	18.00	3.0	131.7
2880	-0.1	67.2	56.0	1.2	1.3	55.1	18.00	3.0	131.8
2910	-0.1	67.1	55.9	1.2	1.3	55.2	18.25	3.0	131.5
2940	0.0	67.2	56.1	1.4	1.3	55.3	18.25	3.0	131.9
2970	-0.1	67.4	56.3	1.2	1.3	55.4	18.25	3.0	132.1
3000	-0.1	67.5	56.4	1.2	1.3	55.5	18.50	3.0	132.3
3030	-0.1	67.6	56.6	1.1	1.3	55.6	18.50	3.0	132.5
3060	0.0	67.6	56.7	1.3	1.3	55.8	18.50	3.0	132.4
3090	0.0	67.7	56.8	1.3	1.3	55.9	18.50	3.0	132.5
3120	0.1	67.8	57.0	1.2	1.3	55.9	18.50	3.0	132.3
3150	-0.1	68.1	57.1	1.2	1.3	56.1	18.50	3.0	132.4
3180	-0.1	67.9	57.1	1.2	1.3	56.1	18.50	3.0	132.6
3210	0.0	68.0	57.2	1.3	1.3	56.2	18.50	3.0	133.2