Brewhouse Calculations

Plato and Specific Gravity
Plato is the weight of extract in a one hundred gram solution at a temperature of 20° C. The original scale was by Balling, but Dr. Plato corrected them. Either % wt./vol (grams/100ml), or % wt./wt. (grams/100 grams). For example:

$$^{0}\text{Plato} = \frac{\text{lb solids}}{\text{100 lb wort}}$$

Specific gravity is the density of one material divided by the density of a reference material, normally water at 4°C. ASBC references are based on water at 20°C. Density is defined as mass per unit volume, so for example units for specific gravity would be:

$$\frac{lb_{material}/bbl_{material}}{lb_{water}/bbl_{water}}$$

The units cancel, and therefore specific gravity is unit-less (which is true for all "specific" measurements.
Although home brewers speak in specific gravity units, and craft brewers often use °Plato, it is actually important to know both units, and how to convert from one to another. There are several ways to do this, and which method you use depends on the level of precision you require. The most general formulas for converting from specific gravity to °Plato are:

$$^{0}\text{Plato} = \frac{(\text{S.G.} - 1) \times 1000}{4}$$

$$\text{S.G.} = 1.0 + (0.004 \times {}^{0}\text{Plato})$$

Within the range of starting gravities we generally brew at, the previous calculations generally hold true.
A more precise calculation to follow is:

$$^{0}\text{Plato} = [(\text{S.G.})^2 (-205.347)] + (668.7183)(\text{S.G.}) - 463.371$$

$$\text{S.G.} = \frac{^{0}\text{Plato}}{258.6 - \left[\frac{^{0}\text{Plato}}{258.2} \times 227.1\right]} + 1.0$$

The following table may also be used:

Values are at 20°C and rounded up
°Plato = degrees Brix = cane sugar % w/w

Specific gravity	°Plato	Specific gravity	°Plato
1.003	0.6	1.047	11.7
1.005	1.3	1.050	12.3
1.007	1.9	1.062	15.3
1.010	2.6	1.065	15.8
1.012	3.2	1.067	16.4
1.015	3.8	1.070	17.0
1.017	4.4	1.087	21.0
1.020	5.1	1.090	21.5
1.022	5.7	1.092	22.0
1.025	6.3	1.095	22.6
1.027	6.9	1.097	23.1
1.030	7.5	1.100	23.7
1.032	8.1	1.102	24.2
1.035	8.7	1.105	24.8
1.037	9.4	1.107	25.3
1.040	10.0	1.110	25.8
1.042	10.6	1.112	26.4
1.045	11.2	1.115	27.0

From Lewis and Young 1995

Why is it so important to be able to know both the specific gravity and °Plato of a wort? Because we will need both of these factors to be able to accurately determine the weight of extract of the wort.

Weight of Extract

The weight of extract is the amount of extract from the malt present in the wort. The formula is:

$$\mathbf{lb_{extract}} = \frac{\mathbf{(258\ lb / 1\ bbl_{wort})\ (bbl_{wort})\ (S.G.)\ (^{0}P)}}{\mathbf{100}}$$

The 258 figure is the weight of a barrel of water, so we must multiply this by the specific gravity of the wort to find the weight of a barrel of wort. You may also use the following equation to avoid having to convert to specific gravity at all.

$$\text{lb}_{extract} = \frac{[(258\text{lb} + {}^{0}\text{P}) / 1\ \text{bbl}_{wort}]\ (\text{bbl}_{wort})\ ({}^{0}\text{P})}{100}$$

By adding the °Plato of the wort to the weight of the barrel we get a good approximation of the weight of a barrel of wort. This formula is not exact, but it is easy to remember, and will work in most situations.

Grist Calculations

Next, we need to determine the actual amount of extract we will get from a particular malt. To calculate this we need to find both the Hot Water Extract for the particular malt, and the Brewhouse Yield for the particular brewhouse we are using.

Brewhouse Yield (BHY) is a percentage that gives the effective "efficiency" of the brewhouse. It is the comparison between the actual extract in the brewery and the Hot Water $\text{Extract}_{as\text{-}is}$ determined in the lab by the malt supplier. Typical BHY for a large brewery might be on the order of 98%, but for most micro-breweries it ranges from 90-95%. We will assume a BHY of 90% for this problem.

Note that BHY may vary not only by brewery, but also by how the material is handled, but often it will be assumed that it is the same for any given brewery. It is a good idea for any brewer to "benchmark" their brewery by making measurements perhaps using a simple brew with just 2 row malt to measure the actual efficiency their brewhouse is capable of realizing.

If we multiply the BHY and the $\text{HWE}_{as\text{-}is}$ we will get the "Working Yield" (WY), that is, the percent of extract we expect to get from the particular malt in our brewhouse.

Working Yield (WY) = Hot Wort $\text{Extract}_{as\text{-}is}$($\text{HWE}_{as\text{-}is}$) x Brewhouse Yield (BHY)

For example:

$$\text{WY} = \text{HWE}_{cg\ as\text{-}is} \times \text{BHY}$$

For a malt with $\text{HWE}_{cg\ as\text{-}is}$ = 77.0%, and in a brewhouse with a measured efficiency of 90% the

$$\text{WY} = 0.77 \times 0.90 = 0.69\%$$

A working yield of 0.69 will mean that for every 1 lb of malt, we will yield 0.69 lb of extract in the wort (in our brewery).

Brewing spec sheets generally give the HWE figure as fine grind dry basis because it gives the biggest number. You can find the HWE course ground dry basis by subtracting the fine course difference number generally also given on the specification sheet. To find the as-is numbers simply multiply the dry basis number by (100% - moisture %)

$$\textbf{HWE}_{\text{c.g. as-is}} = \textbf{HWE}_{\text{c.g.dry basis}}\ \textbf{(1 – moisture)}$$

To find the HWE $_{\text{c.g. dry basis}}$ from the HWE $_{\text{c.g. as-is}}$ number use:

$$\textbf{HWE}_{\text{c.g.dry basis}} = \textbf{HWE}_{\text{c.g. as-is}}\ \textbf{/ (1 – moisture)}$$

It is also important to remember that by definition, working yield is equal to the weight of the extract divided by the raw weight of the malt:

$$\textbf{WY} = \textbf{lb}_{\text{extract}} / \textbf{lb}_{\text{malt}}$$

Note that for the most part, brewers measure by percent extract not by percent raw weight of the malt. To most brewers 10% crystal used in the brew does not mean 10 lb crystal/100 lb Malt, but rather 10% of total extract from crystal malt. This is because each type of malt has its own extract potential. So:

$$\textbf{Weight of malt} = \frac{\textbf{(Total extract weight) (\% of malt type)}}{\textbf{Working Yield}}$$

Finally, we must take into consideration that the °Plato and S.G. readings are calibrated to 20°C, and we will be measuring at 100°C (at the end of the boil). Liquids contract depending on their temperature, and there is about a 4% contraction between 100 and 20°C. So:

Cooled wort collected in the fermenter occupies 96% of the volume it did when it was at boiling point in the kettle.

So we must remember to factor this into the equation to allow for reading the level of the hot wort.

One additional factor would be the use of syrups in the brew. For syrups the brewer assumes 100% BHY, and uses the syrups total solids as the $\text{HWE}_{\text{as-is}}$.

Actual brewhouse yield

To back calculate the BHY after the brew, we must have the actual °Plato from the brew, along with the actual barrels of wort collected.

$$\textbf{BHY}_{\text{actual}} = \frac{({}^{0}\textbf{P}_{\text{actual}})\ (\textbf{bbl}_{\text{actual}})\ (\textbf{BHY}_{\text{target}})}{({}^{0}\textbf{P}_{\text{target}})\ (\textbf{bbl}_{\text{target}})}$$

To calculate the total extract in a brew you must calculate the extract contribution from each ingredient in the brew and simply add them together. When formulating a beer you must calculate the total extract required from the various malts then apply the percentage of extract you require to come from each malt.

Color

Next we will attempt to determine the final beer color from colors of the various malts. The color numbers are supplied by the maltster, who determines them in the lab from the

HWE from the malt. One of the biggest problems encountered is that the gravity of the wort (strength) will greatly affect the final color of the wort. To be able to compensate for this, we must know the gravity of the wort made in the lab, and compare this with the projected gravity of our wort.
The reference worts used to determine the °L (degrees Lovibond) in the lab are about 8°P wort. So we can simply divide the gravity of our wort by the gravity of the reference wort to come up with a factor for color, and multiply this by the % extract and color of the malt to determine the color contributed by that particular malt.

$$(\%\ \text{malt})(\text{color})(°P_{wort}/°P_{reference}) = \text{color from malt}$$

Where:

$$°P_{reference} = 8°P$$

In most cases there will be color contributions from more than one malt, and these will make up the total color for the wort:
Unfortunately, there is also a loss during fermentation and other processing. There is no set amount for this loss, since it depends on fermentation temperatures, yeast type, filtration, oxidation, and many other variables. This is a figure that the brewer must make up from experience and trial and error. It could be anywhere between 20 – 30%. Once this percentage is determined it can be factored into the equation:

$$(\text{color})(1-\text{loss}_{brewery}) = \text{actual color}$$

This will give the final equation for color as:

$$\Sigma\ [(\%\ \text{of total extract})(°L\ \text{of malt})(°P_{wort}/(°P_{reference})(1-\text{loss}_{brewery})] = \text{Color}$$

ie

$$(\%color_1)\ (color_1)\ (^0P_{wort}/^0P_{reference}) = \quad \text{color from malt}_1$$
$$(\%color_2)\ (color_2)\ (^0P_{wort}/^0P_{reference}) = \quad \text{color from malt}_2$$
$$(\%color_3)\ (color_3)\ (^0P_{wort}/^0P_{reference}) = \quad \underline{\text{color from malt}_3}$$
$$\text{Total color}$$

European and British malt will likely report color in EBC units. To convert between EBC and SRM (^{0}L) units use:

$$^0L = (^0EBC + 1.2) / 2.65$$

or:

$$^0L = {}^0EBC / 1.97$$

Strike Water

When laying a mash, you must determine the required strike temperature of the liquor to get a certain mash temperature.

To do this we will use a basic engineering calculation for steady state heat (conservation of energy).

$$M_{malt}\ C_{pmalt}\ \Delta T_{malt} = M_{water}\ C_{pwater}\ \Delta T_{water}$$

M_{malt}	=	**Mass of the malt**
C_{pmalt}	=	**Specific Heat Capacity of the malt**
ΔT_{malt}	=	**Change in the temperature of the malt**
M_{water}	=	**Mass of the water**
C_{pwater}	=	**Specific Heat Capacity of the water**
ΔT_{water}	=	**Change in temperature of the water**

What is ΔT?

ΔT (Delta Temperature) is the change in temperature from the initial temperature to the final temperature. In the case of the malt, it would be the intial temperature of the malt minus the temperature of the mash (which is the final temperature of the malt in this system).

What is C_p?

C_p (Specific heat) is the quantity of heat that is gained or lost by a unit weight of product to accomplish a desired change in temperature, without change in state.

C_p = heat "energy"/mass x temperature
C_p = specific heat (cal/g ^{0}C)

We will use this to determine the required strike temperature of the mash. For malt the C_p is around 0.4 C cal/g°C, and this was determined empirically. The C_p for water is 1 cal/g°C

First we must know the mash thickness, since it affects the mass of the mash:

L:G ratio

$$\mathbf{Mass_{water} : Mass_{malt} = liquor : grist}$$

The equation for getting the bbl of water once you have decided upon the L:G ratio is:

$$bbl_{water} = \frac{(lb_{malt})\,(L{:}G)\,(1\ bbl_{water})}{258\ lb_{water}}$$

Once we have the weight of the water and the grist, we can determine the temperature of the strike water because we will have the following known quantities in the equation:

M_{water}
M_{malt}
C_{pwater}
C_{pmalt}
$T_{initial(malt)}$ = **Measured temperature of the malt** = T_{malt}
$T_{final(malt)}$ = **Temperature of the mash** = T_{mash}
$T_{final(water)}$ = **Temperature of the mash** = T_{water}

The only unknown in the equation will now be the $T_{initial(water)}$ which is the temperature of the strike water.
By manipulating the conservation of energy equation, we come up with this formula for the strike water temperature, which can be used with either °F or °C:

$$T_{water} = \frac{(M_{malt})\,(C_{pmalt})\,(T_{mash} - T_{malt})}{(M_{water})\,(C_{pwater})} + T_{mash}$$

The L:G ratio can be substituted for the M_{water} vs M_{malt}
We can substitute the relative specific heat of malt versus water too

$$Twater = \frac{(0.4)\,(Tmash - Tmalt)}{L{:}G} + T_{mash}$$

Hop Calculations

Hop calculations are fairly simple, but not terribly accurate. The units used for expressing bitterness are IBU's, or International Bittering Units.

IBU = mg iso-α-acids / l beer (same as ppm)

The equation for relating final beer IBU and amount of hops added into the boil is:

$$\text{Wt of hops} = \frac{(l_{wort})(IBU)}{(\%\ \alpha\text{-acids in hops})(\%\ \text{utilization})(1000)}$$

What is the 1000 for?

$$g_{hops} = \frac{(l_{wort})\left(\dfrac{mg_{iso\text{-}\alpha\text{-}acids}}{l_{beer}}\right)}{\left(\dfrac{g_{iso\text{-}\alpha\text{-}acids}}{g_{hops}}\right)\left(\dfrac{mg_{iso\text{-}\alpha\text{-}acids}\ \text{to kettle}}{mg_{iso\text{-}\alpha\text{-}acids}\ \text{in beer}}\right)\left(\dfrac{1000mg}{g}\right)}$$

By adding in conversion factors into American units we can simplify the formula to:

$$lb_{hops} = \frac{(bbl_{beer})\ (IBU_{target})}{(\%\ \alpha\ \text{acid})\ (\%\text{utilization})\ (3868)}$$

Although the previous calculation will work fine for the bittering hops, we may want to use a different calculation for the aroma hops. Since most brewers determine the amount of aroma hops they will use by the aromatic qualities that they desire rather than the bitterness they contribute, and we can manipulate the calculation bitterness calculation to aid in this method of formulation. By first calculating the IBUs contributed by the aroma hops from the weight added, you can determine amount of IBUs of bittering hops you will require.

Remember that for all of these equations the utilization and α-acids must be expressed as a percent (i.e. 0.12). The most difficult part to determine in this equation is the hop utilization rate, which varies depending on many different factors.

For a microbrewery operation, we will generalize all the factors, and use the following tables to estimate utilizations. There are several sources for estimating the utilization efficiencies. This one proved closest in tests to providing results that matched laboratory tests for IBUs

Table 3. Hop Utilization Rates for Final IBU in Beer for Different Boil Times and Wort Gravity[19]

Whole Hop Utilization Rates

	specific gravity						
minutes	1.030	1.040	1.050	1.060	1.070	1.080	1.090
5	5%	5%	4%	4%	3%	3%	3%
15	12%	12%	11%	11%	11%	10%	9%
30	17%	17%	16%	16%	15%	15%	13%
45	21%	21%	20%	19%	18%	17%	16%
60	24%	23%	23%	22%	21%	20%	18%
90	28%	27%	26%	26%	25%	23%	21%

Pellet Hop Utilization Rates

	specific gravity						
minutes	1.030	1.040	1.050	1.060	1.070	1.080	1.090
5	6%	6%	5%	5%	4%	4%	3%
15	15%	15%	14%	14%	13%	13%	11%
30	22%	21%	21%	20%	19%	18%	16%
45	26%	26%	25%	24%	23%	22%	21%
60	29%	28%	28%	27%	26%	25%	23%
90	35%	34%	33%	32%	31%	29%	27%

From A handbook of Brewing calculations by Stephen Holle MBAA
The IBU's calculated from these utilizations may or may not match the laboratory analysis of IBU's for a beer, but they will give a ballpark figure for beer bitterness.