Elliptic Functions: Complex Variables

Introduction

So far we have studied the elliptic functions of real variables, i.e. we consider the u in $\mathrm{sn}(u, k)$ to be a real number and have so far found that they have properties similar to the circular functions (for example they are bounded and periodic). However their real nature and power is exhibited only when we go in the realm of complex numbers and study them as functions of complex variables.

As an example of the power of complex variables, we can see the contrast between real variables and complex variables by looking at the behavior of circular functions and exponential functions. If we limit ourselves to the real variables the functions $\sin x$ and $\cos x$ have nothing to do with the exponential function $\exp(x)$ but as soon as we meet the complex variables we have the remarkable equation $\exp(ix) = \cos x + i \sin x$ and this puts the circular, exponential and logarithmic functions on the same footing.

We will not be discussing the deep methods of complex function theory, but we will rather find some peculiar properties of the elliptic functions when considered as functions of a complex variable. To that end we need to extend the definition of the elliptic functions to the domain of complex arguments. A simple method of defining $\mathrm{sn}(x + iy, k)$ could be define $\mathrm{sn}(iy, k)$ first and then use the addition formulas to define $\mathrm{sn}(x + iy, k)$. This brings us to the now famous Jacobi's Imaginary Transformation.

Jacobi's Imaginary Transformation

We need to recast our definitions in a slightly different form as follows:

$$\begin{aligned} u = F(\phi, k) &= \int_0^{\phi} \frac{d\theta}{\sqrt{1 - k^2 \sin^2 \theta}} \\ &= 2 \int_0^{s} \frac{dt}{\sqrt{1 + 2(1 - 2k^2)t^2 + t^4}} \end{aligned}$$

where $\sin \phi = 2s/(1 + s^2)$.

Thus we have $\mathrm{sn}(u, k) = 2s/(1 + s^2)$ where s and u are related by the integral above. And after some manipulation we have

$$\begin{aligned} \mathrm{cn}(u, k) &= \frac{1 - s^2}{1 + s^2} \\ \mathrm{dn}(u, k) &= \frac{\sqrt{1 + 2(1 - 2k^2)s^2 + s^4}}{1 + s^2} \end{aligned}$$

If we substitute $t = ix$ in the above integral formally and do some manipulation we get

$$iu = 2 \int_0^{is} \frac{dx}{\sqrt{1 + 2(1 - 2k^2)x^2 + x^4}}$$

Elliptic Functions With Complex Arguemen

Tobias Bleicker

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