

# NAG C Library Function Document

## nag\_jacobian\_theta (s21ccc)

### 1 Purpose

nag\_jacobian\_theta (s21ccc) returns the value of one of the Jacobian theta functions  $\theta_0(x, q)$ ,  $\theta_1(x, q)$ ,  $\theta_2(x, q)$ ,  $\theta_3(x, q)$  or  $\theta_4(x, q)$  for a real argument  $x$  and non-negative  $q \leq 1$ .

### 2 Specification

```
double nag_jacobian_theta (Integer k, double x, double q, NagError *fail)
```

### 3 Description

This routine evaluates an approximation to the Jacobian theta functions  $\theta_0(x, q)$ ,  $\theta_1(x, q)$ ,  $\theta_2(x, q)$ ,  $\theta_3(x, q)$  and  $\theta_4(x, q)$  given by

$$\begin{aligned}\theta_0(x, q) &= 1 + 2 \sum_{n=1}^{\infty} (-1)^n q^{n^2} \cos(2n\pi x), \\ \theta_1(x, q) &= 2 \sum_{n=0}^{\infty} (-1)^n q^{(n+\frac{1}{2})^2} \sin\{(2n+1)\pi x\}, \\ \theta_2(x, q) &= 2 \sum_{n=0}^{\infty} q^{(n+\frac{1}{2})^2} \cos\{(2n+1)\pi x\}, \\ \theta_3(x, q) &= 1 + 2 \sum_{n=1}^{\infty} q^{n^2} \cos(2n\pi x), \\ \theta_4(x, q) &= \theta_0(x, q),\end{aligned}$$

where  $x$  and  $q$  (the *nome*) are real with  $0 \leq q \leq 1$ . Note that  $\theta_1(x - \frac{1}{2}, 1)$  is undefined if  $(x - \frac{1}{2})$  is an integer, as is  $\theta_2(x, 1)$  if  $x$  is an integer; otherwise,  $\theta_i(x, 1) = 0$ , for  $i = 0, 1, \dots, 4$ .

These functions are important in practice because every one of the Jacobian elliptic functions (see nag\_jacobian\_elliptic (s21cbc)) can be expressed as the ratio of two Jacobian theta functions (see Whittaker and Watson (1990)). There is also a bewildering variety of notations used in the literature to define them. Some authors (e.g., Abramowitz and Stegun (1972), 16.27) define the argument in the trigonometric terms to be  $x$  instead of  $\pi x$ . This can often lead to confusion, so great care must therefore be exercised when consulting the literature. Further details (including various relations and identities) can be found in the references.

nag\_jacobian\_theta (s21ccc) is based on a truncated series approach. If  $t$  differs from  $x$  or  $-x$  by an integer when  $0 \leq t \leq \frac{1}{2}$ , it follows from the periodicity and symmetry properties of the functions that  $\theta_1(x, q) = \pm \theta_1(t, q)$  and  $\theta_3(x, q) = \pm \theta_3(t, q)$ . In a region for which the approximation is sufficiently accurate,  $\theta_1$  is set equal to the first term ( $n = 0$ ) of the transformed series

$$\theta_1(t, q) = 2\sqrt{\frac{\lambda}{\pi}} e^{-\lambda t^2} \sum_{n=0}^{\infty} (-1)^n e^{-\lambda(n+\frac{1}{2})^2} \sinh\{(2n+1)\lambda t\}$$

and  $\theta_3$  is set equal to the first two terms (i.e.,  $n \leq 1$ ) of

$$\theta_3(t, q) = \sqrt{\frac{\lambda}{\pi}} e^{-\lambda t^2} \left\{ 1 + 2 \sum_{n=1}^{\infty} e^{-\lambda n^2} \cosh(2n\lambda t) \right\},$$

where  $\lambda = \pi^2 / |\log_e q|$ . Otherwise, the trigonometric series for  $\theta_1(t, q)$  and  $\theta_3(t, q)$  are used. For all values of  $x$ ,  $\theta_0$  and  $\theta_2$  are computed from the relations  $\theta_0(x, q) = \theta_3(\frac{1}{2} - |x|, q)$  and  $\theta_2(x, q) = \theta_1(\frac{1}{2} - |x|, q)$ .

## 4 Parameters

- 1: **k** – Integer *Input*  
*On entry:* the function  $\theta_K(x, q)$  to be evaluated. Note that **k** = 4 is equivalent to **k** = 0.  
*Constraint:*  $0 \leq \mathbf{k} \leq 4$ .
- 2: **x** – double *Input*  
*On entry:* the argument  $x$  of the function.  
*Constraints:*  
 $\mathbf{x}$  must not be an integer when **q** = 1.0 and **k** = 2,  
 $(\mathbf{x}-0.5)$  must not be an integer when **q** = 1.0 and **k** = 1.
- 3: **q** – double *Input*  
*On entry:* the argument  $q$  of the function.  
*Constraint:*  $0.0 \leq \mathbf{q} \leq 1.0$ .
- 4: **fail** – NagError \* *Input/Output*  
The NAG error parameter (see the Essential Introduction).

## 5 Error Indicators and Warnings

### NE\_INT

On entry, **k** = *<value>*.  
Constraint:  $0 \leq \mathbf{k} \leq 4$ .

### NE\_REAL

On entry, **q** = *<value>*.  
Constraint:  $0.0 \leq \mathbf{q} \leq 1.0$ .  
On entry, **x** = *<value>*.  
Constraint:  $(\mathbf{x}-0.5)$  must not be an integer when **q** = 1.0 and **k** = 1.  
On entry, **x** = *<value>*.  
Constraint: **x** must not be an integer when **q** = 1.0 and **k** = 2.

### NE\_INFINITE

The evaluation has been abandoned because the function value is infinite.

### NE\_INTERNAL\_ERROR

An internal error has occurred in this function. Check the function call and any array sizes. If the call is correct then please consult NAG for assistance.

## 6 Further Comments

### 6.1 Accuracy

In principle the routine is capable of achieving full relative precision in the computed values. However, the accuracy obtainable in practice depends on the accuracy of the C standard library elementary functions such as sin and cos.

## 6.2 References

Abramowitz M and Stegun I A (1972) *Handbook of Mathematical Functions* Dover Publications (3rd Edition)

Whittaker E T, and Watson G N (1990) *A Course in Modern Analysis* Cambridge University Press (4th Edition)

Magnus W, Oberhettinger F and Soni R P (1966) *Formulas and Theorems for the Special Functions of Mathematical Physics* 371–377 Springer-Verlag

Tölke F (1966) *Praktische Funktionenlehre (Bd. II)* 1–38 Springer-Verlag

Byrd P F and Friedman M D (1971) *Handbook of Elliptic Integrals for Engineers and Scientists* 315–320 Springer-Verlag (2nd Edition)

## 7 See Also

None.

## 8 Example

The example program evaluates  $\theta_2(x, q)$  at  $x = 0.7$  when  $q = 0.4$ , and prints the results.

### 8.1 Program Text

```
/* nag_jacobian_theta (s21ccc) Example Program.
 *
 * Copyright 2000 Numerical Algorithms Group.
 *
 * NAG C Library
 *
 * Mark 6, 2000.
 */

#include <stdio.h>
#include <nag.h>
#include <nag_stdlib.h>
#include <nags.h>

int main(void)
{
    const char fmt_99999[] = "%2ld  %4.1f  %4.1f %12.4e\n";
    double q, x, y;
    Integer exit_status=0;
    Integer k;
    NagError fail;

    INIT_FAIL(fail);
    Vprintf("s21ccc Example Program Results\n\n");

    /* Skip heading in data file */
    Vscanf("%*[^\\n] ");
    Vprintf(" k      x      q      y\n\n");
    while (scanf("%ld%lf%lf%*[^\\n]", &k, &x, &q) != EOF)
    {
        y = s21ccc (k, x, q, &fail);
        if (fail.code == NE_NOERROR)
            Vprintf(fmt_99999, k,x,q,y);
        else
        {

```

```
        Vprintf("Error from s2lccc.\n%s\n", fail.message);
        exit_status = 1;
        goto END;
    }
}
END:
    return exit_status;
}
```

## 8.2 Program Data

s2lccc Example Program Data

2 0.7 0.4 : Values of k, x and q

## 8.3 Program Results

s2lccc Example Program Results

k	x	q	y
2	0.7	0.4	-6.9289e-01

---