



```

for m := 1 step 1 until n do
  begin
    iteration:
    Horner (a, b, n, x0, pp, qq); x1 := x0 - pp/qq;
    if abs(x1 - x0) > eps × abs(x1) then
      begin x0 := x1;
        comment x0 is the last approximation for the zero
          being improved, which may be printed out at this
          point;
        go to iteration;
      end;
    z[m] := x1;
    comment z[m] := x1 is the mth zero of the polynomial;
    pp := b[0] := b[0] - aa; q[0] := pp;
    if m < n then
      begin for i := 1 step 1 until n-1 do
        begin pp := p[i] := x1 × p[i-1] + a(i);
          pp := b[i] := b(i) - pp;
          q[i] := x1 × q[i-1] + pp;
        end;
        Horner (p, q, n-1, x1, pp, qq);
        x0 := x1 - pp/qq;
        comment x0 is a first approximation for the
          next zero;
      end
    end
  end Newton Maehly;

```

ALGORITHM 106  
 COMPLEX NUMBER TO A REAL POWER  
 MARGARET L. JOHNSON AND WARD SANGREN  
 Computer Applications, Inc., San Diego, California

```

procedure POWC (x, y, w, A, B); value x, y, w;
  real x, y, w, A, B;
  comment This procedure takes a complex number (x+iy) to
  a real power w. The result is A+iB = (x+iy)w. This procedure
  must be used with caution because although it is formally cor-
  rect, it may not give the desired results. For example, if w is a
  reciprocal integer it does not follow that the desired power
  (a root) will be calculated;
  begin real THETA, PHI, R;
  if x > 0 then begin THETA := 0.0; go to SOL 1 end;
  if x < 0 ∧ y ≥ 0 then begin THETA := 3.1415927;
  go to SOL 1 end;
  if x < 0 ∧ y < 0 then begin THETA := 3.1415927;
  go to SOL 1 end;
  if x = 0 ∧ y = 0 then begin A := B := 0.0; go to RETURN end;
  if x = 0 ∧ y < 0 then begin PHI := 1.5707963; go to SOL 2 end;
  if x = 0 ∧ y > 0 then begin PHI := -1.5707963;
  go to SOL 2 end;
  SOL 1: PHI := arctan (y/x) + THETA;
  SOL 2: R := sqrt (x×x + y×y);
  R := exp (w×ln(R));
  A := R×cos (w×PHI);
  B := R×sin (w×PHI);
  RETURN: end POWC

```

ALGORITHM 107  
 GAUSS'S METHOD  
 JAY W. COUNTS  
 University of Missouri, Columbia, Mo.

```

procedure gauss (u, a, y);
  real array a, y; real temp; integer u;

```

```

  comment This procedure is for solving a system of
  linear equations by successive elimination of the un-
  knowns. The augmented matrix is a and u the number of
  unknowns. The solution vector is y. If the system hasn't
  any solution or many solutions, this is indicated by go
  to stop;
  begin
    integer i, j, k, m, n;
    n := 0;
  ck0: n := n+1;
    for k := n step 1 until u do if a[k, n] ≠ 0 then go to ck1;
    go to stop;
  ck1: if k = n then go to ck2;
    for m := n step 1 until u+1 do
      begin
        temp := a[n, m]; a[n, m] := a[k, m]; a[k, m] := temp
      end;
  ck2: for j := u+1 step -1 until n do a[n, j] := a[n, j]/a[n, n];
    for i := k+1 step 1 until u do
      for j := n+1 step 1 until u+1 do
        a[i, j] := a[i, j] - a[i, n] × a[n, j];
      if n ≠ u then go to ck0;
      for i := u step -1 until 1 do
        begin
          y[i] := a[i, u+1]/a[i, i];
          for k := i-1 step -1 until 1 do
            a[k, u+1] := a[k, u+1] - a[k, i] × y[i]
          end end;

```

ALGORITHM 108  
 DEFINITE EXPONENTIAL INTEGRALS A  
 YURI A. KRUGLYAK  
 Kharkov State University, Kharkov, U.S.S.R., AND  
 DONALD R. WHITMAN  
 Case Institute of Technology, Cleveland, Ohio

```

real procedure As (n, b); value n, b; integer n; real b;
  comment: This procedure computes a value of integral
  An-1(1, b) = ∫1∞ xn-1 exp(-bx) dx for any given positive integer, n,
  and any positive real parameter, b, by the recursion formula
  An(1, b) = A0(1, b) + (n/b)An-1(1, b) with A0(1, b) = exp(-b)/b;
  begin integer m; real db; real array a[1:n];
  a[1] := exp (-b)/b;
  if n = 1 then go to exit;
  comment integral a[1] = A0(1, b) was evaluated;
  db := 1/b; for m := 2 step 1 until n do a[m] :=
  a[1] + db × (m-1) × a[m-1];
  comment integral a[n] = An-1(1, b) was evaluated;
  As := a[n] end As;

```

ALGORITHM 109  
 DEFINITE EXPONENTIAL INTEGRALS B  
 YURI A. KRUGLYAK  
 Kharkov State University, Kharkov, U.S.S.R., AND  
 DONALD R. WHITMAN  
 Case Institute of Technology, Cleveland, Ohio

```

real procedure Bs(n, a); value n, a; integer n; real a;
  comment This procedure computes a value of the integral
  Bn-1(a) = ∫-1+1 xn-1 exp(-ax) dx for any given positive integer, n,
  and any real parameter, a. If |a| < alim an expansion of
  exp(-ax) is used, otherwise the recursion formula Bn(a) =
  [(-1)nea - e-a + nBn-1(a)]/a with b0(a) = 2 sinh(a)/a is used. The
  value of alim depends upon the highest n appearing in the

```

calculations and upon the maximum errors in the last significant digits in the library procedures. For example, we have used  $\text{alim}=8$  for  $n_{\max}=16$  with  $\text{gamma}=1\times 10^{-8}$ . The intrinsic function  $\text{mod}(E_1, E_2)$  which requires two integer arguments, is the conventional modulus;

```

begin    integer m; real alim, delta, gamma, r, epsilon,
          s, k, a2, omega, da, jp, jm, q1, q2; real array
          b[1:n]; if a=0 then
L1:      begin if mod(n-1, 2)=0 then
L2:      begin b[n] := 2/n; go to exit end L2;
comment integral b[n] =  $B_{n-1}(0)$  for odd n was evaluated;
          b[n] := 0; go to exit end L1;
comment integral b[n] =  $B_{n-1}(0)$  for even n was evaluated;
          if abs(a) alim then
L3:      begin delta := gamma; if mod(n-1, 2)=0 then
L4:      begin r := 2/n; epsilon := r×delta; s := r;
          k := 0; a2 := a↑2;
Even:    k := k+2;
          r := r×a2×(n+k-2)/(k×(k-1)×(n+k));
          s := s+r; if r>epsilon then go to Even;
          b[n] := s+r;
          go to exit end L4;
comment integral b[n]= $B_{n-1}(a)$  for odd n and |a|<alim was
          evaluated;
          r := 2×a/(n+1); omega := abs(r×delta);
          s := r; k := 1;
          a2 := a↑2;
Odd:    k := k+2;
          r := r×a2×(n+k-2)/(k×(k-1)×(n+k));
          s := s+r; if abs(r)>omega then go to Odd;
          b[n] := -(s+r); go to exit end L3;
comment integral b[n]= $B_{n-1}(a)$  for even n and |a|<alim was
          evaluated;
          da := 1/a; jp := da×exp(a); jm := (da↑2)/jp;
          b[1] := jp-jm;
          if n=1 then go to exit;
comment integral b[1] =  $B_0(a)$  for |a|≥alim was evaluated;
          q1 := -1; q2 := 1; for m := 2 step 1 until n do
L5:      begin b[m] := q1×jp-jm+q2×da×b[m-1];
          q1 := -q1; q2 := q2+1 end L5;
comment integral b[n]= $B_{n-1}(a)$  for integer n≥2 and |a|≥alim
          was evaluated;
exit:    Bs := b[n] end Bs;

```

## ALGORITHM 110

### QUANTUM MECHANICAL INTEGRALS OF SLATER-TYPE ORBITALS

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```

real procedure INTSOLI (n, r, za, ab, As, Bs) Result:
(s, i1, i2, i3); value n, r, za, zb; integer n; real r, za, zb;
real array a[1:8], b[1:8], G[1:2×n]; integer array bc[1:2×n,
1:2×n]; real procedure As, Bs;

```

**comment** Procedure INTSOLI computes the quantum mechanical integrals  $s = \langle \psi_{n00}^{ai} | \psi_{210}^{bi} \rangle$  (overlap integral),  $i1 = \langle \psi_{n00}^{ai} | Z_a^*/r_{ai} | \psi_{210}^{bi} \rangle$  (exchange integral),  $i2 = \langle \psi_{n00}^{ai} | Z_b^*/r_{bi} | \psi_{n00}^{ai} \rangle$  (coulomb integral), and  $i3 = \langle \psi_{210}^{bi} | Z_a^*/r_{ai} | \psi_{210}^{bi} \rangle$  (coulomb integral).

Here  $|\psi_{nlm}^{ai}\rangle$  is a Slater-type orbital of electron  $i$  centered on atomic nucleus  $a$ . The integer  $n$  is the effective principal quantum number with values 1, 2, 3 and 4.  $Z_a^*=za$  and  $Z_b^*=zb$  are effective nuclear charges.  $r_{bi}$  is the distance of electron

$i$  from nucleus  $b$ . The input parameter  $r$  is the distance between the two centers  $a$  and  $b$ . All physical quantities are given in atomic units;

```

begin    integer q, t, c, m;
          real g, zsa, zsb, ks, p, pt, lilya, s, k1, exc, i1, pppt,
          k2, sue, i2, pmpt, ptmp, k3, i3;
          bc[1, 1] := bc[2, 1] := bc[2, 2] := 1;
          for q := 3 step 1 until 2×n do
L6:      begin bc[g, 1] := 1; for t := 2 step 1 until g-1 do
          bc[q, t] := bc[q-1, t-1]+bc[q-1, t];
          bc[q, q] := 1 end L6;
comment binomial coefficients  $bc[q, t] = \binom{q-1}{t-1}$  were computed
          using the recursion formula  $\binom{q}{t} = \binom{q-1}{t-1} + \binom{q-1}{t}$ ;
procedure As(n, b) Result: (a[n]); value n, b; integer n;
real b;
comment procedure As computes a value of integral  $A_{n-1}(1, b)$ 
[see Algorithm 108, "Definite Exponential Integrals A," by Yuri A. Kruglyak and D. R. Whitman, Comm. ACM (July 1962)]. Any identifier occurring within the As is specified to be local to the As;
begin    integer m; real db; a[1] := exp(-b)/b;
          if n=1 then go to exitAs; db := 1/b;
          for m := 2 step 1 until n do a[m] := a[1] +
          db×(m-1)×a[m-1]
exitAs: end As;
procedure Bs(n, a) Result: (b[n]); value n, a; integer n;
real a;
comment procedure Bs computes a value of integral  $B_{n-1}(a)$ 
[see Algorithm 109, "Definite Exponential Integrals B" by Yuri A. Kruglyak and D. R. Whitman, Comm. ACM (July 1962)]. Any identifier occurring within the Bs is specified to be local to the Bs;
begin    integer m; real alim, delta, gamma, r, epsilon,
          s, k, a2, omega, da, up, jm, q1, q2;
          if a=0 then begin if mod(n-1, 2)=0
then begin b[n] := 2/n; go to exitBs end;
          b[n] := 0; go to exitBs end;
          if abs(a)<alim then begin delta := gamma;
comment we have used alim=8 and gamma=1×10-8;
          if mod(n-1, 2)=0 then begin r := 2/n;
          epsilon := r×delta;
          s := r; k := 0; a2 := a↑2;
Even:    k := k+2;
          r := r×a2×(n+k-2)/((k×(k-1)×(n+k)));
          s := s+r; if r>epsilon then go to Even;
          b[n] := s+r;
          go to exitBs end; r := 2×a/(n+1);
          omega := abs(r×delta);
          s := r; k := 1; a2 := a↑2;
Odd:    k := k+2;
          r := r×a2×(n+k-2)/(k×(k-1)×(n+k));
          s := s+r; if abs(r)>omega then go to Odd;
          b[n] := -(s+r); go to exitBs end; da := 1/a;
          jp := da×exp(a);
          jm := (da↑2)/jp; b[1] := jp-jm;
          if n=1 then go to exitBs;
          q1 := -1; q2 := 1; for m := 2 step 1 until n
do begin b[m] := q1×jp-jm+q2×da×b[m-1];
          q1 := -q1; q2 := q2+1 end
exitBs: end Bs;
          g := 1; for m := 1 step 1 until 2×n do g := g/m;
          G[2×n] := g;
comment 1/(2n)! = G[2×n] was evaluated;
          zsa := za/n; zsb := zb/2; ks := (r/2)↑(n+3)×
          (2×zsa)↑(n+1/2)×zsb↑(5/2)×G[2×n]↑(1/2);
          p := r×(zsa+zsb)/2;

```

```

pt := r*(zsa-zsb)/2;
  for c := 1 step 1 until n+3 do
ABSI:  begin As(c, p) Result: (a[c]);
        Bs(c, pt) Result: (b[c])
  end ABSI;
S:     lilya := 0; for m := 0 step 1 until n do lilya :=
        lilya+bc[n+1, m+1]*(a[n-m+2]*(b[m+1]+
        b[m+3])-b[m+2]*(a[n-m+1]+a[n-m+3]));
        s := ks*lilya;
II:    k1 := ks*za/r; exc := 0;
        for m := 0 step 1 until n-1 do
exc := exc+bc[n, m+1]*(a[n-m+1]*(b[m+1]+
        b[m+3])-b[m+2]*(a[n-m]+a[n-m+2]));
        il := k1*exc;
I2:    pppt := p+pt; k2 := (r/2)^(2*n)*(2*za)^(
        2*n+1)*zsb*G[2*n];
        for c := 1 step 1 until 2*n do
BA2:   begin As(c, pppt) Result: (a[c]);
        Bs(c, pppt) Result: (b[c])
  end BA2; sue := 0;
        for m := 0 step 1 until 2*n-1 do
sue := sue+bc[2*n, m+1]*a[2*n-m]*b[m+1];
i2 := k2*sue;
I3:    pmpt := p-pt; ptmp := -pmpt;
        k3 := (r/2)^(4*2*za*zsb)^5;
        for c := 1 step 1 until 4 do
AB3:   begin As(c, pmpt) Result: (a[c]);
        Bs(c, ptmp) Result: (b[c])
  end AB3; i3 := k3*(a[2]*(b[1]+2*b[3])-b[2]*
        (a[1]+2*a[3])+a[4]*b[3]-a[3]*b[4]) end
INTSOLI;

```

### ALGORITHM 111 MOLECULAR-ORBITAL CALCULATION OF MOLECULAR INTERACTIONS

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**real procedure** SOLI(n, za, zb, rem, coef2, r1, E1, dr1, drk1, acc, acc1, rk2, rk1, dr2, asy, rk3, dr3, As, Bs, RESULT) Result: (ra, Ep, Em, ca, ca2, cb, cb2, DEa, DEb, s, i1, i2, i3, haa, hab, hbb); value n, za, zb, rem, coef2, r1, E1, dr1, rk1, drk1, acc, acc1, rk2, dr2, asy, rk3, dr3; integer n, rem; real otherwise; real array a[1:8], b[1:8], G[1:8], zsap [1:9], rp[1:8], ans[1:rem]; real procedure As, Bs, RESULT;

**comment** This procedure calculates a one-electron approximation to the energy of interaction of molecular species by the use of the molecular-orbital (MO) method with a linear combination of Slater-type orbitals (LCSTO). The wave function used is  $|\phi\rangle = c_a |\psi_{n00}^a\rangle + c_b |\psi_{210}^b\rangle$ , where  $|\psi_{n1m}^a\rangle$  is a STO centered on nucleus  $a$ . The effective principal quantum number  $n$  takes the integral value 1, 2, 3 or 4. The Hamiltonian used is:  $\mathcal{H}_{ab} = -\Delta/2 - Z_a^*/r_a - Z_b^*/r_b + Z_a^*Z_b^*/R_{ab}$ . Here  $Z_a^*$  and  $Z_b^*$  are effective nuclear charges,  $r_a$  and  $r_b$  the distances of the electron from nucleus  $a$  and  $b$ , and  $R_{ab}$  is the distance between nuclei  $a$  and  $b$ . The calculations are in atomic units, while the output  $ra$  is in Angstroms and  $DEa$  and  $DEb$  are in kcal/gm-ion. Abbreviations of the following type are used:  $Za = Z_a^*$ ,  $ra = R_{ab}(\text{\AA})$ ,  $haa = \langle \psi_{n00}^a | \mathcal{H}_{ab} | \psi_{n00}^a \rangle$ ,  $DEa = D(a, b + \text{electron})$ ,  $e1 = \langle \psi_{n00}^a | -\Delta/2 - Z_a^*/r_a | \psi_{n00}^a \rangle$ . The values of coef1 and coef2 are 627.71 (kcal/gm-ion) and 0.5291\AA, respectively.  $r1, E1, dr1, dr2, dr3, acc, acc1$ , and  $asy$  are control parameters. The accuracy of the calculations ( $acc, acc1$ ) is  $1 \times 10^{-5}$ . The

initial values of  $R_{ab}$  and  $E_{ab}$  are conveniently:  $r1 = 0.4(\text{\AA})$ , and  $E1 = 100(\text{a.u.})$ . The steps are:  $dr1 = 0.1$ ,  $dr2 = 0.4$ , and  $dr3 = 0.01$ , all in Angstroms.  $asy$  is  $-1 \times 10^{-3}$  (a.u.);

```

begin integer q, t, c, m, f; real otherwise;
procedure As(n, b) Result: (a[n]); value n, b; integer n;
  real b;
comment any identifier occurring within the As is specified
  to be local to the As;
begin integer m; real db; a[1] := exp(-b)/b;
  if n=1 then go to exitAs; db := 1/b;
  for m := 2 step 1 until n do a[m] := a[1]+db*(
    m-1)*a[m-1]
exitAs: end As;
procedure Bs(n, a) Result: (b[n]); value n, a; integer n;
  real a;
comment any identifier occurring within the Bs is specified
  to be local to the Bs;
begin integer m; real otherwise; if a=0 then begin if
  mod(n-1, 2)=0 then begin b[n] := 2/n;
  go to exitBs end; b[n] := 0; go to exitBs end;
  if abs(a)<alim then begin delta := gamma;
  if mod(n-1, 2)=0 then begin r := 2/n;
  epsilon := r*delta; s := r; k := 0; a2 := a^2;
  k := k+2; r := r*a2*(n+k-2)/(k(k-1)(n+k));
  s := s+r; if r>epsilon then go to Even;
  b[n] := s+r; go to exitBs end;
  r := 2*a/(n+1); omega := abs(r*delta);
  s := r; k:=1; a2 := a^2;
  k := k+2; r := r*a2*(n+k-2)/(k(k-1)(n+k));
  s := s+r; if abs(r)>omega then go to Odd;
  b[n] := -(s+r); go to exitBs
end; da := 1/a; jp := da*exp(a);
  jm := (da^2)/jp; b[1] := jp-jm;
  if n=1 then go to exitBs; q1 := -1; q2 := 1;
  for m := 2 step 1
  until n do begin b[m] := q1*jp-jm+
    q2*da*b[m-1];
  q1 := -q1; q2 := q2+1 end
exitBs: end Bs;
procedure Result(coef1); real coef1;
comment RESULT computes Ep, Em, ca, ca2, cb, cb2, DEa,
  DEb, s, i1, i2, i3, nn, haa, hab, hbb. Important:
  RESULT and any identifier occurring within the
  RESULT enter SOLI as nonlocal entities;
begin r := ra*br; rp[1] := r; for c := 2 step 1 until
  n+4 do rp[c] := rp[c-1]*rp[1]; p := r*sum;
  pt := r*dif; ks := rp[n+3]*zss;
  for c := 1 step 1 until n+3 do begin As(c, p)
  Result: (a[c]); Bs(c, pt) Result: (b[c]) end;
  lilya := 0; for m := 0 step 1 until n do lilya :=
  lilya+bc[n+1, m+1]*(a[n-m+2]*(
  b[m+1]+b[m+3])-b[m+2]*(a[n-m+1]
  +a[n-m+3])); s := ks*lilya; lii2 := 2*s;
  k1 := ks*za/r; exc := 0; for m := 0 step 1
  until n-1 do exc := exc+bc[n, m+1]*(a[n-
  m+1]*(b[m+1]+b[m+3])-b[m+2]*(a[n-m]+
  a[n-m+2])); il := k1*exc; pppt := p+pt;
  k2 := rp[2*n]*zsb; for c := 1 step 1 until
  2*n do begin As(c, pppt) Result: (a[c]);
  Bs(c, pppt) Result: (b[c]) end; sue := 0;
  for m := 0 step 1 until 2*n-1 do sue :=
  sue+bc[2*n, m+1]*a[2*n-m]*b[m+1];
  i2 := k2*sue; pmpt := p-pt;
  ptmp := -pmpt; k3 := rp[4]*z5;
  for c := 1 step 1 until 4 do begin As(c, pmpt)
  Result: (a[c]); Bs(c, ptmp) Result: (b[c]) end;
  i3 := k3*(a[2]*(b[1]+2*b[3])-b[2]*(a[1]+2*
  a[3])+a[4]*b[3]-a[3]*b[4]);

```

**comment** Two-center integrals  $s$ ,  $i1$ ,  $i2$ , and  $i3$  were computed [see Algorithm 110, "Quantum Mechanical Integrals of Slater-Type Orbitals," by Yuri A. Kruglyak and D. R. Whitman, *Comm. ACM* (July 1962)];  $nn := zz/(2 \times r)$ ;  $e2pnn := e2 + nn$ ;  $haa := e1 - e2 + nn$ ;  $hbb := e2pnn - i3$ ;  $hab := e2pnn \times s - i1$ ;  $den := 2 - s \times li12$ ;  $bsr := haa + hbb - hab \times li12$ ;  $root := \sqrt{bsr^2 - 2 \times den \times (haa \times hbb - hab^2)}$ ;  $Ep := (bsr + root)/den$ ;  $Em := (bsr - root)/den$ ;  $ans[f] := Em$ ;  $DEa := coef1 \times (e2 - Em)$ ;  $DEb := coef1 \times (e1 - Em)$ ;  $Emhaa := Em - haa$ ;  $Emhbb := Em - hbb$ ;  $ES := Em \times s$ ;  $habmES := hab - ES$ ;  $caDcb1 := habmES/Emhaa$ ;  $cbDca2 := habmES/Emhbb$ ; **if**  $abs(Emhaa) > abs(Emhbb)$  **then begin**  $col := caDcb1^2$ ;  $cb2 := 1/(1 + li12 \times caDcb1 + col)$ ;  $ca2 := cb2 \times col$ ;  $ca := \sqrt{ca2}$ ;  $cb := ca/caDcb1$  **go to NATA end**;  $co2 := cbDca2^2$ ;  $ca2 := 1/(1 + li12 \times cbDca2 + co2)$ ;  $cb2 := ca2 \times co2$ ;  $ca := \sqrt{ca2}$ ;  $cb := ca \times cbDca2$   
**NATA: end RESULT**;  
**Begin of program:**  $bc[1, 1] := bc[2, 1] := bc[2, 2] := 1$ ;  
**for**  $q := 3$  **step 1 until 8 do begin**  $bc[q, 1] := 1$ ; **for**  $t := 2$  **step 1 until**  $q-1$  **do**  $bc[q, t] := bc[q-1, t-1] + bc[q-1, t]$ ;  $bc[q, q] := 1$  **end**;  
**IZM:**  $g := 1$ ; **for**  $m := 1$  **step 1 until**  $2 \times n$  **do**  $g := g/m$ ;  $G[2 \times n] := g$ ;  $zsa := za/n$ ;  $zsa[1] := zsa \times 2$ ; **for**  $c := 2$  **step 1 until**  $2 \times n + 1$  **do**  $xsa[c] := zsa[c-1] \times zsa[1]$ ;  $D := zsa[2 \times n + 1] \times G[2 \times n]$ ;  $DS := \sqrt{D}$ ;  $e1 := -zsa[2] \times 0.125 \times (4 \times n - 3)/(2 \times n - 1)$ ;  $zsb := zb \times 0.5$ ;  $sum := zsa + zsb$ ;  $dif := zsa - zsb$ ;  $zsb5 := zsb^5$ ;  $zss := DS \times \sqrt{zsb5}$ ;  $zsbD := zsb \times D$ ;  $z5 := 2 \times za \times zsb5$ ;  $zz := za \times zb$ ;  $e2 := -(zsb^2)/2$ ;  $br := 0.5/coef2$ ;  $f := 1$ ;  $ans[1] := E1$ ;  $ra := r1$ ;  
**KOM:**  $ra := ra + dr1$ ; **if**  $ra > rk1$  **then**  $ra := ra + drk1$ ;  $f := f + 1$ ; **RESULT** ( $coef1$ ); **if**  $ans[f] - ans[f-1] \leq acc$  **then begin** **if**  $ra > rk2$  **then go to IZM**; **go to KOM end**;  $ansf := ans[f]$ ;  $d1 := ra$ ;  
**CLEV:**  $ra := ra + dr2$ ; **RESULT** ( $coef1$ ); **if**  $e1 < e2$  **then begin** **if**  $Em - e1 \leq asy \wedge ra < rk3$  **then go to CLEV**; **go to KHAR end**; **if**  $e1 \geq e2$  **then begin** **if**  $Em - e2 \leq asy \wedge ra < rk3$  **then go to CLEV**; **go to KHAR end**;  
**KHAR:**  $ra := d1$ ;  $ansf-1 := ansf$ ;  
**CASE:**  $ra := ra - dr3$ ;  $f := f + 1$ ; **RESULT** ( $coef1$ ); **if**  $ans[f] - ans[f-1] \leq acc1$  **then go to CASE**; **go to IZM end SOLI**;

#### REMARK ON ALGORITHM 34

GAMMA FUNCTION [M. F. Lipp, *Comm. ACM* 4 (Feb. 1961)]

MARGARET L. JOHNSON AND WARD SANGREN  
 Computer Applications, Inc., San Diego, Calif.

The coefficients used in the calculation of the Hasting's polynomial are used in reverse order. The algorithm should have  
 $a[1] = -.19352782$ ;  $a[2] = .48219939$ ;  $a[3] = -.75670408$ ;  
 $a[4] = .91820686$ ;  $a[5] = -.89705694$ ;  $a[6] = .98820589$ ;  
 $a[7] = -.57719165$ ;  $a[8] = 1.0$ ;  
 $y = .03586834$ ;

**for**  $i := 1$  **step 1 until 8 do**  $y := y \times x + a[i]$ ;

Further, since  $\Gamma(x) = \Gamma(1+x)$ , the divisor  $x$  in the statement labeled minus should be  $x+1$ .

#### REMARK ON ALGORITHM 48

LOGARITHM OF A COMPLEX NUMBER [John R. Herndon, *Comm. ACM* 4 (Apr. 1961)]

MARGARET L. JOHNSON AND WARD SANGREN  
 Computer Applications, Inc., San Diego, Calif.

Considerable care must be taken in using the arctan function. In Algorithm 48 two such difficulties are ignored. First, it is necessary, because of a resulting division by zero, to deal separately with the case where the real part of the complex number is zero. Second, if the real part of the complex number is negative and the argument of the logarithm is to have a value between  $-\pi$  and  $\pi$  then the action depends upon the sign of the imaginary part of the complex number. For clarity the following procedure exhibits in sequence the alternatives:

**procedure** LOGC ( $a, b, c, d$ ); **value**  $a, b$ ; **real**  $a, b, c, d$ ;  
**comment** This procedure computes the number  $c+di$  which is equal to  $\log_e(a+bi)$ . It is assumed that the arctan has a value between  $-\pi/2$  and  $\pi/2$ .

**begin** **if**  $a > 0$  **then begin**  $THETA := 0$ ; **go to SOL end**;  
**if**  $a < 0 \wedge b \geq 0$  **then begin**  $THETA := 3.1415927$ ;  
**go to SOL end**;  
**if**  $a < 0 \wedge b < 0$  **then begin**  $THETA := -3.1415927$ ;  
**go to SOL end**;  
**if**  $a = 0 \wedge b = 0$  **then begin**  $c := d := 0$ ;  
**go to RETURN end**;  
**if**  $a = 0 \wedge b > 0$  **then begin**  $c := \ln(b)$ ;  $d := 1.570963$ ;  
**go to RETURN end**;  
**if**  $a = 0 \wedge b < 0$  **then begin**  $c := \ln(abs(b))$ ;  
 $d := 1.570963$ ; **go to RETURN end**;  
**SOL:**  $d := \arctan(b/a) + THETA$ ;  
 $c := \sqrt{a^2 + b^2}$ ;  
 $c := \ln(c)$ ;

**RETURN: end LOGC**

#### CERTIFICATION OF ALGORITHM 51

ADJUST INVERSE OF A MATRIX WHEN AN ELEMENT IS PERTURBED [John R. Herndon, *Comm. ACM* 4 (Apr. 1961)]

RICHARD GEORGE\*

Argonne National Laboratory, Argonne, Ill.

This procedure was programmed in FORTRAN and reduced to machine code mechanically. It was run on the Argonne-built computing machine, GEORGE. A floating-point routine was used which allows maximum accuracy to 31 bits.

The procedure was tested for matrices with  $n$  ranging from 2 to 10. For each value of  $n$ , there were 20 successive trials; each trial consisted of a random perturbation of a randomly selected element of the matrix  $M$ , followed by a use of ADJUST, followed by the matrix multiplication  $N := B \cdot M$ . For each trial, the adjustment was evaluated by computing

$$\text{sum} := \left\{ \sum_{i=1}^n \sum_{j=1}^n N[i, j] \right\} - n.$$

For random perturbations between  $-1.0$  and  $+1.0$ , the value of sum never exceeded  $2.0_{10} - 8$ .

There are two typographical errors present:

$$B[r, s] = A[r, s] - t \times A[r, i] \times A[j, s] \text{ end}$$

should be

$$B[r, s] := A[r, s] - t \times A[r, i] \times A[j, s] \text{ end}$$

\* Work supported by the U. S. Atomic Energy Commission.

CERTIFICATION OF ALGORITHM 57  
 BER OR BEI FUNCTION [J. R. Herndon, *Comm. ACM*  
 4 (Apr. 1961)]

A. P. RELPH  
 The English Electric Co. Whetstone, England

Algorithm 57 was translated using the DEUCE ALGOL compiler.  
 No corrections were required, and the results were satisfactory.

CERTIFICATION OF ALGORITHM 70  
 INTERPOLATION BY AITKEN [C. J. Mifsud, *Comm.*  
*ACM* 4 (Nov. 1961)]

A. P. RELPH  
 The English Electric Co., Whetstone, England

Algorithm 70 was translated using the DEUCE ALGOL compiler  
 and gave satisfactory results after semicolons had been added to

$t := j+1$  to make it  $t := j+1$ ;

and  $(x[i]-x[j])$  end to make it  $(x[i]-x[j])$  end;

The identifier  $t$  can be eliminated and the algorithm shortened  
 by the following changes:

Replace **begin integer**  $i, j, t$ ; by **begin integer**  $i, j$ ;  
 Replace  $t := j+1$ ; by **for**  $i := j+1$  **step 1 until**  
 $n$  **do**  
 $\text{for } i := t \text{ step 1 until } n \text{ do}$

CERTIFICATION OF ALGORITHM 75  
 FACTORS [J. E. L. Peck, *Comm. ACM* 5 (Jan. 1962)]

A. P. RELPH  
 The English Electric Co., Whetstone, England

Algorithm 75 was translated using the DEUCE ALGOL compiler  
 and gave satisfactory results after the following corrections had  
 been made:

**begin if**  $q=0 \vee (an \div q) \times q = an$  **then**  
**begin if**  $q > 1 \wedge p = 1$  **then**

was changed to

**begin if**  $q \leq 1$  **then go to** NO CONSTANT;  
**if**  $(an \div q) \times q = an$  **then**  
**begin if**  $p = q$  **then**

**begin**  $c := c \times a_0$ ;  $a_0 := 1$   
**end**

was changed to

**begin**  $c := c \times a[0]$ ;  $a[0] := 1$ ;  
**end**

There are now  $r$  ( $r > 0$ ) rational linear factors  $(u_i x - v_i)$ ,  
 $1 < i < r$ ,

was changed to

If  $r > 0$  there are now  $r$  rational linear factors  $(u_i x - v_i)$ ,  $1 \leq i \leq r$ ,

To return to the state ( $p=1, q=0$ ) after every factor or constant  
 is found is inefficient. This can be avoided by substituting  $a[0]$   
 and  $a[n]$  for the identifiers  $a_0$  and  $a_n$  respectively. The procedure  
 then becomes:

**procedure** factors ( $n, a, u, v, r, c$ ); **value**  $n, a$ ;  
**integer array**  $a, u, v$ ;  
**integer**  $r, n, c$ ;  
**begin integer**  $p, q$ ;  
 $r := 0$ ;  $c := 1$ ;  
 ZERO: **if**  $a[n]=0$  **then**  
**begin**  $r := r+1$ ;  $u[r] := 1$ ;  $v[r] := 0$ ;  $n := n-1$ ;  
**go to** ZERO  
**end**;  
**for**  $p := 1$  **step 1 until**  $\text{abs}(a[0])$  **do**  
**begin if**  $(a[0] \div p) \times p = a[0]$  **then**  
**begin for**  $q := 1$  **step 1 until**  $\text{abs}(a[n])$  **do**  
**begin if**  $q=1$  **then go to** NO CONSTANT;  
 TRY AGAIN: **if**  $(a[n] \div q) \times q = a[n]$  **then**  
**begin integer**  $j$ ;  
**for**  $j := 0$  **step 1 until**  $n-1$  **do**  
**if**  $(a[j] \div q) \times q \neq a[j]$  **then go to**  
 NO CONSTANT;  
**for**  $j := 0$  **step 1 until**  $n$  **do**  
 $a[j] := a[j]/q$ ;  
 $c := c \times q$ ; **go to** TRY AGAIN  
**end**;  
 NO CONSTANT: **begin integer**  $f, g, i$ ;  $f := a[0]$ ;  
 $g := 1$ ;  
**for**  $i := 1$  **step 1 until**  $n$  **do**  
**begin**  $g := g \times p$ ;  
 $f := f \times q + a[i] \times g$   
**end**;  
**if**  $f=0$  **then**  
**begin**  $r := r+1$ ;  $u[r] := p$ ;  
 $v[r] := q$ ;  
**begin integer**  $i, t$ ;  $t := 0$ ;  
**for**  $i := 0$  **step 1 until**  $n$  **do**  
**begin**  $a[i] := t := (a[i]+t)/p$ ;  
 $t := t \times q$   
**end**;  
 $n := n-1$   
**end**  
**go to if**  $n=0$  **then** REDUCED  
**else** NO CONSTANT  
**end**;  
 $q := -q$ ; **if**  $q < 0$  **then go to** NO  
 CONSTANT  
**end**

**end**  
**end**  
**end**;  
 REDUCED: **if**  $n=0$  **then**  
**begin**  $c := c \times a[0]$ ;  $a[0] := 1$   
**end**

**end**

CERTIFICATION OF ALGORITHM 84  
 SIMPSON'S INTEGRATION [P. E. Hennion, *Comm.*  
*ACM* 5 (Apr. 1962)]

A. P. RELPH  
 The English Electric Co., Whetstone, England

Simpson's Integration was translated using the DEUCE ALGOL  
 compiler and, with no corrections, gave satisfactory results.

It is not stated in the comment that integer  $n$  needs to be even.

CERTIFICATION OF ALGORITHM 108  
 DEFINITE EXPONENTIAL INTEGRALS A [Yuri  
 A. Kruglyak and Donald R. Whitman, *Comm. ACM* 5  
 (July 1962)]

YURI A. KRUGLYAK  
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 DONALD R. WHITMAN  
 Case Institute of Technology, Cleveland, Ohio

Integrals  $A_n(1,b) = \int_1^\infty x^n \exp(-bx) dx$  occur in physical problems involving spheroidal coordinates, particularly in quantum chemistry calculations. This algorithm was programmed for the Burrough's 220 computer using Burrough's Algebraic Compiler. The program was used to compute tables of  $A_n(1,b)$  in the ranges  $n=0(1)15$ , and  $b=0.01(0.01)30.14$ . For example, for  $n=0(1)15$ , and  $b=0.25$  and  $b=24.0$ , the results below were obtained. These are compared with the results (columns 3 and 5) obtained by James Miller, John M. Gerhauser, and F. A. Matsen [*Quantum Chemistry Integrals and Tables*, University of Texas Press, 1959].

n	b=0.25 (Miller et al.)		b=24.0 (Miller et al.)	
	b=0.25	b=24.0	b=0.25	b=24.0
0	.31152031, 01	.31152031322856, 01	.15729727, -11	.15729727267830, -11
1	.15576015, 02	.15576015661428, 02	.16385132, -11	.16385132570656, -11
2	.12772332, 03	.12772332842371, 03	.17095154, -11	.17095154982051, -11
3	.15357950, 04	.15357951442168, 04	.17866621, -11	.17866621640586, -11
4	.24575835, 05	.24575837510601, 05	.18707497, -11	.18707497541261, -11
5	.49151976, 06	.49151986541516, 06	.19627122, -11	.19627122588926, -11
6	.11796476, 08	.11796479885167, 08	.20636507, -11	.20636507915061, -11
7	.33030132, 09	.33030143989988, 09	.21748707, -11	.21748708743056, -11
8	.10569642, 11	.10569646079911, 11	.22979295, -11	.22979296848848, -11
9	.38050711, 12	.38050725887992, 12	.24346962, -11	.24346963586148, -11
10	.15220284, 14	.15220290355200, 14	.25874294, -11	.25874295428724, -11
11	.66969248, 15	.66969277562880, 15	.27588778, -11	.27588779339328, -11
12	.32145238, 17	.32145233230182, 17	.29524115, -11	.29524116937404, -11
13	.16715523, 19	.16715531679695, 19	.31721955, -11	.31721957275639, -11
14	.93606928, 20	.93606977406291, 20	.34234200, -11	.34234202345285, -11
15	.56164156, 22	.56164186443775, 22	.37126102, -11	.37126103733633, -11

The accuracy is at least six significant figures over the entire range. This accuracy is completely satisfactory for all quantum chemical calculations.

CERTIFICATION OF ALGORITHM 109  
 DEFINITE EXPONENTIAL INTEGRALS B [Yuri A.  
 Kruglyak, D. R. Whitman, *Comm. ACM* 5 (July 1962)]

YURI A. KRUGLYAK  
 Kharkov State University, Kharkov, U.S.S.R., and  
 DONALD R. WHITMAN  
 Case Institute of Technology, Cleveland, Ohio

Integrals  $B_n(a) = \int_{-1}^{+1} x^n \exp(-ax) dx$  occur in physical problems involving spheroidal coordinates, particularly in quantum chemistry calculations. This algorithm was programmed for the Burroughs-220 computer using a Burroughs Algebraic Compiler. The program was used to compute tables of  $B_n(a)$  in the ranges  $n=0(1)15$ , and  $a=0.00(0.01)32.54$ . For example, for  $n=0(1)15$  and  $a=0.25$ , and  $a=24.0$  the results below were obtained. These are compared with the results (columns 3 and 5) obtained by James Miller, John M. Gerhauser, and F. A. Matsen [*Quantum Chemistry Integrals and Tables*, University of Texas Press, Austin, 1959].

n	a=0.25 (Miller et al.)		a=24.0 (Miller et al.)	
	a=0.25	a=24.0	a=0.25	a=24.0
0	.20208984, 01	.20208985344653, 01	.11037134, 10	.110371342208, 10
1	-.16771064, 00	-.16771066117520, 00	-.10577253, 10	-.105772536282, 10
2	.67921322, 00	.67921324506375, 00	.10155696, 10	.101556964184, 10
3	-.10074584, 00	-.10074585827159, 00	-.97676725, 09	-.976767216847, 09
4	.40896479, 00	.40896480211998, 00	.94091887, 09	.940918885936, 09
5	-.72008754, -01	-.72008756636929, -01	-.90768866, 09	-.907688654174, 09
6	.29268836, 00	.29268837517905, 00	.87679129, 09	.876791258533, 09
7	-.56030292, -01	-.56030294023170, -01	-.84798262, 09	-.847982638338, 09
8	.22792911, 00	.22792912573392, 00	.82105258, 09	.821052542631, 09
9	-.45856272, -01	-.45856272975402, -01	-.79581870, 09	-.795818718590, 09
10	.18664760, 00	.18664761544688, 00	.77212229, 09	.772122289331, 09
11	-.38809718, -01	-.38809719373731, -01	-.74982404, 09	-.749824039467, 09
12	.15803198, 00	.15803200452627, 00	.72880141, 09	.728801402343, 09
13	-.33640562, -01	-.33640563670387, -01	-.70894600, 09	-.708945995807, 09
14	.13702696, 00	.13702696892367, 00	.69016158, 09	.690161591189, 09
15	-.29686662, -01	-.29686663616401, -01	-.67236245, 09	-.672362427583, 09

The accuracy is at least six significant figures in the ranges mentioned above. This accuracy is enough for the majority of quantum chemistry calculations.

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Input		K. and W. Result	Preuss' Result				
n	r		Notation	Table No.			
1	5	0.5 0.2	s	0.14841691	[1a 3b]	0.148417	23
1	1	4.5 8.0	s	0.35203437	[1a 3b] 10 10	0.352034	30
2	1	20 20	s	0.25032133×10 <sup>-1</sup>	[2a 3b]	0.250321×10 <sup>-1</sup>	40
1	5	0.5 0.2	i1	0.22058816	5[a <sup>-1</sup>   1a 3b] 4.5 4.0	0.220588	59
1	1	4.5 8.0	i1	0.96587055	1[a <sup>-1</sup>   1a 3b] 10 10	0.965871	66
2	1	20 20	i1	0.58102500×10 <sup>-1</sup>	1[a <sup>-1</sup>   2a 3b]	0.581025×10 <sup>-1</sup>	76
1	1	0.5 0.2	i2	0.44818080	1[b <sup>-1</sup>   1a 1a] 0.5 0.5	0.448181	41
1	5	0.5 0.2	i2	0.97641725	5[b <sup>-1</sup>   1a 1a] 10 10	0.976417	45
2	1	20 20	i2	0.99999530	1[b <sup>-1</sup>   2a 2a]	0.100000×10 <sup>1</sup>	58
1	1	10 1	i3	0.26217432	1[b <sup>-1</sup>   3a 3a] 5 5	0.262174	41
1	1	10 10	i3	0.11093011×10 <sup>1</sup>	1[b <sup>-1</sup>   3a 3a] 10 10	0.110929×10 <sup>1</sup>	50
1	1	10 20	i3	0.10300137×10 <sup>1</sup>	1[b <sup>-1</sup>   3a 3a]	0.103001×10 <sup>1</sup>	58

CERTIFICATION OF ALGORITHM 110  
 QUANTUM MECHANICAL INTEGRALS OF  
 SLATER-TYPE ORBITALS [Yuri A. Kruglyak and  
 Donald R. Whitman, *Comm. ACM* 5 (July 1962)]

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 DONALD R. WHITMAN  
 Case Institute of Technology, Cleveland, Ohio

This procedure was written and tested in the Burroughs 220 version of the ALGOL language in the spring of 1961 at Case Institute of Technology. The program was used to compute tables of quantum mechanical integrals  $s$ ,  $i1$ ,  $i2$ , and  $i3$  in the ranges:  $r(\text{Å})=0.64(0.02)1.40(0.10)3.10$ ;  $Z_b^*=0.25(0.50)3.75, 3.90, 4.25, 4.55, 4.75, 5.20, 5.25$ ;  $Z_a^*=0.7, 1.0$  for  $n=1$ ;  $1.3(1.0)3.3$  for  $n=2$ ;  $0.2, 2.2(1.0)4.2$  for  $n=3$ ; and  $0.2, 2.2, 3.2$  for  $n=4$ . The table at the right shows typical results compared with values from *Integraltafeln zur Quantenchemie* by H. Preuss (Springer-Verlag, 1957), Zweiter Band. Accuracy is at least six significant figures in the ranges mentioned above. This is ample for the overwhelming majority of quantum chemistry calculations.