In[ ]:=

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(*Title:Compton Scattering Calculation Author:[
  Hirokaxzu Maruyama]
  Date:January 2025 Description:
   This code compares Compton scattering calculations
    using:
     1. Conventional 4x4 gamma matrices
      2. Extended 256x256 gamma matrices in
      Minkowski spacetime
      3. Extended 256x256 gamma matrices in curved
      spacetime*)



(*Key Variables:m=mass
   gu[μ]=gamma matrices (upper index)
    gd[μ]=gamma matrices (lower index)
     sl[q]=Dirac slash notation for momentum q*)

(*Step 1:Calculate scattering amplitude using
  conventional method*)
(*Step 2:Convert to Mandelstam variables*)
(*Step 3:Calculate differential cross section*)


(*Results
 Interpretation:
  -The conventional calculation yields Klein-
   Nishina formula-The 256x256 calculation in
    Minkowski space reproduces the conventional result-
   The curved space calculation shows deviations
    due to metric effects*)

Print[Style["Example of Compton scattering calculation",
   Blue]];
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```
Print[
  "************************************************
    **********************************************
    "];
Print[
  Style[
   "1.Compton scattering calculation using 4 γ
     matrices (4*4) (conventional calculation)",
   Blue]];
(*γ matrix(4×4)*)
m =.;
gu[0] = {{1, 0, 0, 0}, {0, 1, 0, 0}, {0, 0, -1, 0},
   {0, 0, 0, -1}};
gu[1] = {{0, 0, 0, 1}, {0, 0, 1, 0}, {0, -1, 0, 0},
   {-1, 0, 0, 0}};
gu[2] = {{0, 0, 0, -I}, {0, 0, I, 0}, {0, I, 0, 0},
   {-I, 0, 0, 0}};
gu[3] = {{0, 0, 1, 0}, {0, 0, 0, -1}, {-1, 0, 0, 0},
   {0, 1, 0, 0}};
e4 = IdentityMatrix[4];

gd[0] = 1 * gu[0];
gd[1] = -gu[1];
gd[2] = -gu[2];
gd[3] = -gu[3];

sl[q] = gu[0] * q0 + gu[1] * (-q1) + gu[2] * (-q2) +
   gu[3] * (-q3) + m * e4;
sl[p] = gu[0] * p0 + gu[1] * (-p1) + gu[2] * (-p2) +
   gu[3] * (-p3) + m * e4;
sl[k] = gu[0] * k0 + gu[1] * (-k1) + gu[2] * (-k2) +
   gu[3] * (-k3);
sl[j] = gu[0] * j0 + gu[1] * (-j1) + gu[2] * (-j2) +
   gu[3] * (-j3);
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```
ms = m * e4;

s1 = 0; y1 = 0;
s2 = 0; y2 = 0;
s3 = 0; y3 = 0;
s4 = 0; y4 = 0;

For[x = 0, x ≤ 3, x++,
  For[y = 0, y ≤ 3, y++,
   (*f(s,u)*)
   s1 = Tr[(sl[q]).gu[x].(sl[p] + sl[k]).gu[y].
      (sl[p]).gd[y].(sl[p] + sl[k]).gd[x]];
   (*g(s,u)*)
   s2 = Tr[(sl[q]).gu[y].(sl[p] - sl[j]).gu[x].
      (sl[p]).gd[x].(sl[p] - sl[j]).gd[y]];
   (*f(u,s)*)
   s3 = Tr[(sl[q]).gu[x].(sl[p] + sl[k]).gu[y].
      (sl[p]).gd[x].(sl[p] - sl[j]).gd[y]];
   (*g(s,u)*)
   s4 = Tr[(sl[q]).gu[y].(sl[p] - sl[j]).gu[x].
      (sl[p]).gd[y].(sl[p] + sl[k]).gd[x]];

   y1 = Simplify[y1 + s1, TimeConstraint → 5000];
   y2 = Simplify[y2 + s2, TimeConstraint → 5000];
   y3 = Simplify[y3 + s3, TimeConstraint → 5000];
   y4 = Simplify[y4 + s4, TimeConstraint → 5000];
  ]];

γ =.;
T1 =
  Simplify[
   y1 //. {p1 → 0, p2 → 0, k0 → p3, k1 → 0, k2 → 0,
     k3 → -p3, q0 → p0, q1 → p3 * Sqrt[1 - z^2], q2 → 0,
     q3 → p3 * z, j0 → p3, j1 → -p3 * Sqrt[1 - z^2],
     j2 → 0, j3 → -p3 * z, p0 → (s + m^2) / (2 Sqrt[s]),
     p3 → (s - m^2) / (2 Sqrt[s]), z → 1 + t / (2 p3^2),
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      t → 2 m^2 - s - u}]; (*f(s,u)*)
T2 =
  Simplify[
   y2 //. {p1 → 0, p2 → 0, k0 → p3, k1 → 0, k2 → 0,
     k3 → -p3, q0 → p0, q1 → p3 * Sqrt[1 - z^2], q2 → 0,
     q3 → p3 * z, j0 → p3, j1 → -p3 * Sqrt[1 - z^2],
     j2 → 0, j3 → -p3 * z, p0 → (s + m^2) / (2 Sqrt[s]),
     p3 → (s - m^2) / (2 Sqrt[s]), z → 1 + t / (2 p3^2),
     t → 2 m^2 - s - u}]; (*g(s,u)*)

T3 =
  Simplify[
   y3 //. {p1 → 0, p2 → 0, k0 → p3, k1 → 0, k2 → 0,
     k3 → -p3, q0 → p0, q1 → p3 * Sqrt[1 - z^2], q2 → 0,
     q3 → p3 * z, j0 → p3, j1 → -p3 * Sqrt[1 - z^2],
     j2 → 0, j3 → -p3 * z, p0 → (s + m^2) / (2 Sqrt[s]),
     p3 → (s - m^2) / (2 Sqrt[s]), z → 1 + t / (2 p3^2),
     t → 2 m^2 - s - u}]; (*f(u,s)*)

T4 =
  Simplify[
   y4 //. {p1 → 0, p2 → 0, k0 → p3, k1 → 0, k2 → 0,
     k3 → -p3, q0 → p0, q1 → p3 * Sqrt[1 - z^2], q2 → 0,
     q3 → p3 * z, j0 → p3, j1 → -p3 * Sqrt[1 - z^2],
     j2 → 0, j3 → -p3 * z, p0 → (s + m^2) / (2 Sqrt[s]),
     p3 → (s - m^2) / (2 Sqrt[s]), z → 1 + t / (2 p3^2),
     t → 2 m^2 - s - u}]; (*g(u,s)*)


Print["f(s,u) ; ", T1];
Print["g(s,u) ; ", T2];
Print["f(u,s) ; ", T3];
Print["g(u,s) ; ", T4];

T5 = (m^2 / (s - m^2) ^2) *
   (1 * (T1 * (1 / (s - m^2) ^2) +
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        (T3 + T4) * (1 / ((s - m^2) * (u - m^2))) +
        T2 * (1 / (u - m^2) ^2)));
T6 = Pi * T5 * dt;
T7 = FullSimplify[
   ExpandAll[T6 /. s → 2 * m * w0 + m^2 /. u → -2 * m * w + m^2 /.
     dt → (1 / Pi) * w^2]];
T8 =
  T7 /. Solve[(w0 - w) / (w0 * w) == 1 / m * (1 - Cos[theta]),
     m] // Simplify;
y1 = FullSimplify[
   T8 /. w → w0 * u / (u + w0 (1 - Cos[theta])) /. w0 → γ * u /.
    u → m];
y2 = y1 /. theta → kakudo /. γ → 0.173 /. kakudo → 0;
T9 = T8 / y2;
Print[
  "Scattering cross section of laboratory system
    (conventional calculation) ; ", T9];
y3 = y1 / y2;
γ = 0.173;
Print["γ=0.173 ; ", y3];
(*Scattering cross section for laboratory system
 (for γ=0.173)*)

Print["γ=0.173"];
Plot[y3, {theta, 0, Pi}, PlotStyle → Blue,
 AspectRatio → 0.75, Frame → True,
 PlotRange → {Degree * {0, 180}, {0, 1}},
 FrameLabel →
  {"Θ", dΦ / Labeled[dΩ, Subsuperscript["γ", 0, 2], Left]},
 FrameTicks →
  {{Table[{t, PaddedForm[t, {4, 2}]}, {t, 0, 1, 0.25}],
    None}, {Degree * Table[t, {t, 0, 180, 30}], None}},
 GridLines → {Degree * Table[t, {t, 0, 180, 30}],
   Table[t, {t, 0, 1, 0.25}]}]
```

```
Print[
  "***************************************************
    ***************************************************
    "];
Print[
  Style[
   "2.Compton scattering calculation using γ
     matrix (256*256)", Blue]];


(*γ matrix(256×256)*)
(*Find 16 combinations of γ matrices (256×256)
 that satisfy the anticommutative relationship*)
demoteRank4to2[y_] :=
  Flatten[Map[Flatten, Transpose[y, {1, 3, 2, 4}], {2}],
   1];
pauli8times[g1_, g2_, g3_, g4_, g5_, g6_, g7_, g8_] :=
  demoteRank4to2[
   Outer[Times, demoteRank4to2[
     Outer[Times, demoteRank4to2[Outer[Times, g1, g2]],
      demoteRank4to2[Outer[Times, g3, g4]]]],
    demoteRank4to2[
     Outer[Times, demoteRank4to2[Outer[Times, g5, g6]],
      demoteRank4to2[Outer[Times, g7, g8]]]]]];


g[1] = {{1, 0}, {0, -1}};
g[2] = {{0, -I}, {I, 0}};
g[3] = {{0, 1}, {1, 0}};
g[0] = {{1, 0}, {0, 1}};

e256 = IdentityMatrix[256];


γuv[0] = pauli8times[g[0], g[0], g[0], g[0], g[0],
   g[0], g[0], g[3]];
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```
γuv[1] =
  I * pauli8times[g[0], g[0], g[0], g[0], g[3], g[2],
    g[2], g[2]];
γuv[2] =
  I * pauli8times[g[0], g[0], g[0], g[1], g[2], g[2],
    g[2], g[2]];
γuv[3] =
  I * pauli8times[g[0], g[0], g[3], g[2], g[2], g[2],
    g[2], g[2]];

γuv[4] =
  I * pauli8times[g[0], g[0], g[0], g[0], g[0], g[0],
    g[0], g[1]];
γuv[5] =
  I * pauli8times[g[0], g[0], g[0], g[0], g[0], g[0],
    g[3], g[2]];
γuv[6] =
  I * pauli8times[g[1], g[2], g[2], g[2], g[2], g[2],
    g[2], g[2]];
γuv[7] =
  I * pauli8times[g[0], g[0], g[1], g[2], g[2], g[2],
    g[2], g[2]];

γuv[8] =
  I * pauli8times[g[0], g[0], g[0], g[0], g[0], g[3],
    g[2], g[2]];
γuv[9] =
  I * pauli8times[g[0], g[0], g[0], g[0], g[0], g[0],
    g[1], g[2]];
γuv[10] =
  I * pauli8times[g[3], g[2], g[2], g[2], g[2], g[2],
    g[2], g[2]];
γuv[11] =
  I * pauli8times[g[0], g[0], g[0], g[0], g[1], g[2],
    g[2], g[2]];
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γuv[12] =
  I * pauli8times[g[0], g[0], g[0], g[0], g[0], g[1],
    g[2], g[2]];
γuv[13] =
  I * pauli8times[g[0], g[1], g[2], g[2], g[2], g[2],
    g[2], g[2]];
γuv[14] =
  I * pauli8times[g[0], g[3], g[2], g[2], g[2], g[2],
    g[2], g[2]];
γuv[15] =
  I * pauli8times[g[0], g[0], g[0], g[3], g[2], g[2],
    g[2], g[2]];


num =
  115 792 089 237 316 195 423 570 985 008 687 907 853 269 984 665 \
   640 564 039 457 584 007 913 129 639 936;

(*Confirm determinant*)

(*16 γ matrices (256×256) Calculation to confirm
 that the anticommutative relationship is satisfied*)

yt = 0;
For[kh = 0, kh ≤ 15, kh++,
  For[ks1 = 0, ks1 ≤ 15, ks1++,
   yf = Det[γuv[kh].γuv[ks1] + γuv[ks1].γuv[kh]];
   yt = yf + yt;
   If[kh =! = ks1 && yf == num * 16,
    Print["No.", km, ",x=", kh, ",y=", ks1]];
  ]];

If[kh == 16 && ks1 == 16 && yt / num == 16, Print[""],
  Print[
   "γ matrix (256*256) 16 pieces Anti-commutation
     relation confirmation NG"]];
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```
(*Set weighing*)

Print[
  Style[
   "2.1.Calculation using 4 γ matrices (256*256)
     under Minkowski spacetime", Blue]];

gd[0] = 1;
gd[1] = 1;
gd[2] = 1;
gd[3] = 1;
gd[4] = 0;
gd[5] = 0;
gd[6] = 0;
gd[7] = 0;
gd[8] = 0;
gd[9] = 0;
gd[10] = 0;
gd[11] = 0;
gd[12] = 0;
gd[13] = 0;
gd[14] = 0;
gd[15] = 0;

m256 = 1 * m;


(*γ matrix multiplied by metric*)

For[km1 = 0, km1 ≤ 15, km1 ++,
  γu[km1] = -gd[km1] * γuv[km1];
 ];
```

```
For[km2 = 0, km2 ≤ 15, km2++,
  γd[km2] = 1 * γu[km2];
 ];
γd[0] = -1 * γu[0];


metric =
  {{-gd[0], gd[10], gd[12], gd[14]},
    {gd[11], gd[1], gd[4], gd[6]},
    {gd[13], gd[5], gd[2], gd[8]},
    {gd[15], gd[7], gd[9], gd[3]}} / gd[0];

Print["Calculate the metric tensor as",
  MatrixForm[metric]];

Print["det (determinant of the metric tensor) =",
  Det[metric]];


sl[q] = (γu[0] * q0 + γu[1] * -q1 + γu[2] * -q2 +
    γu[3] * -q3 + m256 * e256);
sl[p] = (γu[0] * p0 + γu[1] * -p1 + γu[2] * -p2 +
    γu[3] * -p3 + m256 * e256);
sl[k] = (γu[0] * k0 + γu[1] * -k1 + γu[2] * -k2 + γu[3] * -k3);
sl[j] = (γu[0] * j0 + γu[1] * -j1 + γu[2] * -j2 + γu[3] * -j3);


s10 = 0; y10 = 0;
s20 = 0; y20 = 0;
s30 = 0; y30 = 0;
s40 = 0; y40 = 0;
```

```
For[x = 0, x ≤ 3, x++,
  For[y = 0, y ≤ 3, y++,
   (*f(s,u)*)
   s10 = Tr[(sl[q]).γu[x].(sl[p] + sl[k]).γu[y].
      (sl[p]).γd[y].(sl[p] + sl[k]).γd[x]];
   (*g(s,u)*)
   s20 = Tr[(sl[q]).γu[y].(sl[p] - sl[j]).γu[x].
      (sl[p]).γd[x].(sl[p] - sl[j]).γd[y]];
   (*f(u,s)*)
   s30 = Tr[(sl[q]).γu[x].(sl[p] + sl[k]).γu[y].
      (sl[p]).γd[x].(sl[p] - sl[j]).γd[y]];
   (*g(u,s)*)
   s40 = Tr[(sl[q]).γu[y].(sl[p] - sl[j]).γu[x].
      (sl[p]).γd[y].(sl[p] + sl[k]).γd[x]];

   y10 = Simplify[y10 + s10, TimeConstraint → 5000];
   y20 = Simplify[y20 + s20, TimeConstraint → 5000];
   y30 = Simplify[y30 + s30, TimeConstraint → 5000];
   y40 = Simplify[y40 + s40, TimeConstraint → 5000];
  ]];




(*Conversion using Mandelstam variables*)

γ =.;
T10 = Simplify[y10 / ((m256 / m) ^8) //.
    {p1 → 0, p2 → 0, k0 → p3, k1 → 0, k2 → 0, k3 → -p3,
     q0 → p0, q1 → p3 * Sqrt[1 - z^2], q2 → 0, q3 → p3 * z,
     j0 → p3, j1 → -p3 * Sqrt[1 - z^2], j2 → 0,
     j3 → -p3 * z, p0 → (s + m^2) / (2 Sqrt[s]),
     p3 → (s - m^2) / (2 Sqrt[s]), z → 1 + t / (2 p3^2),
     t → 2 m^2 - s - u}, TimeConstraint → 5000];
T20 = Simplify[y20 / ((m256 / m) ^8) //.
    {p1 → 0, p2 → 0, k0 → p3, k1 → 0, k2 → 0, k3 → -p3,
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      q0 → p0, q1 → p3 * Sqrt[1 - z^2], q2 → 0, q3 → p3 * z,
      j0 → p3, j1 → -p3 * Sqrt[1 - z^2], j2 → 0,
      j3 → -p3 * z, p0 → (s + m^2) / (2 Sqrt[s]),
      p3 → (s - m^2) / (2 Sqrt[s]), z → 1 + t / (2 p3^2),
      t → 2 m^2 - s - u}, TimeConstraint → 5000];
T30 = Simplify[y30 / ((m256 / m) ^8) //.
     {p1 → 0, p2 → 0, k0 → p3, k1 → 0, k2 → 0, k3 → -p3,
      q0 → p0, q1 → p3 * Sqrt[1 - z^2], q2 → 0, q3 → p3 * z,
      j0 → p3, j1 → -p3 * Sqrt[1 - z^2], j2 → 0,
      j3 → -p3 * z, p0 → (s + m^2) / (2 Sqrt[s]),
      p3 → (s - m^2) / (2 Sqrt[s]), z → 1 + t / (2 p3^2),
      t → 2 m^2 - s - u}, TimeConstraint → 5000];
T40 = Simplify[y40 / ((m256 / m) ^8) //.
     {p1 → 0, p2 → 0, k0 → p3, k1 → 0, k2 → 0, k3 → -p3,
      q0 → p0, q1 → p3 * Sqrt[1 - z^2], q2 → 0, q3 → p3 * z,
      j0 → p3, j1 → -p3 * Sqrt[1 - z^2], j2 → 0,
      j3 → -p3 * z, p0 → (s + m^2) / (2 Sqrt[s]),
      p3 → (s - m^2) / (2 Sqrt[s]), z → 1 + t / (2 p3^2),
      t → 2 m^2 - s - u}, TimeConstraint → 5000];


Print["f(s,u) ; ", T10];
Print["g(s,u) ; ", T20];
Print["f(u,s) ; ", T30];
Print["g(u,s) ; ", T40];


T50 = (m^2 / (s - m^2) ^2) *
    (1 * (T10 * (1 / (s - m^2) ^2) +
        (T30 + T40) * (1 / ((s - m^2) * (u - m^2))) +
        T20 * (1 / (u - m^2) ^2)));
 T60 = Pi * T50 * dt;
T70 = FullSimplify[
    ExpandAll[
     T60 /. s → 2 * m * w0 + m^2 /. u → -2 * m * w + m^2 /.
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      dt → (1 / Pi) * w^2]];
T80 =
  T70 /. Solve[(w0 - w) / (w0 * w) == 1 / m * (1 - Cos[theta]),
     m] // Simplify;
y10 = FullSimplify[
   T80 /. w → w0 * u / (u + w0 (1 - Cos[theta])) /. w0 → γ * u /.
    u → m];
y20 = y10 /. theta → kakudo /. γ → 0.173 /. kakudo → 0;
T90 = T80 / y20;
Print[
  "Scattering cross section of laboratory system
    (consistent with conventional calculation
    results) ; ", T90];
y30 = y10 / y20;
γ = 0.173;
Print["Same as above (when γ=0.173) ; ", y30];



Print[
  "**************************************************
    ************************************************
    "];

Print[
  Style[
   "2.2.Trial calculation example using 16 γ
     matrices (256*256) in curved space-time",
   Blue]];


gd[0] = 999 / 1000;
gd[1] = 1;
gd[2] = 1;
gd[3] = 1;
gd[4] = 1 / 1000;
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gd[5] = 1 / 1000;
gd[6] = 1 / 1000;
gd[7] = 1 / 1000;
gd[8] = 1 / 1000;
gd[9] = 1 / 1000;
gd[10] = 1 / 1000;
gd[11] = 1 / 1000;
gd[12] = 1 / 1000;
gd[13] = 1 / 1000;
gd[14] = 1 / 1000;
gd[15] = 1 / 1000;

m256 = 1 * m;




(*γ matrix multiplied by metric*)

For[km1 = 0, km1 ≤ 15, km1++,
  γu[km1] = -gd[km1] * γuv[km1];
 ];


For[km2 = 0, km2 ≤ 15, km2++,
  γd[km2] = 1 * γu[km2];
 ];
γd[0] = -1 * γu[0];


metric =
  {{-gd[0], gd[10], gd[12], gd[14]},
    {gd[11], gd[1], gd[4], gd[6]},
    {gd[13], gd[5], gd[2], gd[8]},
    {gd[15], gd[7], gd[9], gd[3]}} / gd[0];
```

```
Print["Calculate the metric tensor as ",
  MatrixForm[metric]];

Print["det (determinant of the metric tensor)=",
  Det[metric]];



s100 = 0; y100 = 0;
s200 = 0; y200 = 0;
s300 = 0; y300 = 0;
s400 = 0; y400 = 0;

sl[q] = (γu[0] * q0 + γu[1] * -q1 + γu[2] * -q2 +
    γu[3] * -q3 + m256 * e256);
sl[p] = (γu[0] * p0 + γu[1] * -p1 + γu[2] * -p2 +
    γu[3] * -p3 + m256 * e256);
sl[k] = (γu[0] * k0 + γu[1] * -k1 + γu[2] * -k2 + γu[3] * -k3);
sl[j] = (γu[0] * j0 + γu[1] * -j1 + γu[2] * -j2 + γu[3] * -j3);

For[x = 0, x ≤ 15, x++,
  For[y = 0, y ≤ 15, y++,
   (*f(s,u)*)
   s100 = Tr[(sl[q]).γu[x].(sl[p] + sl[k]).γu[y].
      (sl[p]).γd[y].(sl[p] + sl[k]).γd[x]];
   (*g(s,u)*)
   s200 = Tr[(sl[q]).γu[y].(sl[p] - sl[j]).γu[x].
      (sl[p]).γd[x].(sl[p] - sl[j]).γd[y]];
   (*f(u,s)*)
   s300 = Tr[(sl[q]).γu[x].(sl[p] + sl[k]).γu[y].
      (sl[p]).γd[x].(sl[p] - sl[j]).γd[y]];
   (*g(u,s)*)
   s400 = Tr[(sl[q]).γu[y].(sl[p] - sl[j]).γu[x].
      (sl[p]).γd[y].(sl[p] + sl[k]).γd[x]];

   y100 = Simplify[y100 + s100, TimeConstraint → 5000];
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   y200 = Simplify[y200 + s200, TimeConstraint → 5000];
   y300 = Simplify[y300 + s300, TimeConstraint → 5000];
   y400 = Simplify[y400 + s400, TimeConstraint → 5000];
  ]];

(*Conversion using Mandelstam variables*)


γ =.;
T100 = Simplify[y100 / ((m256 / m) ^8) //.
    {p1 → 0, p2 → 0, k0 → p3, k1 → 0, k2 → 0, k3 → -p3,
     q0 → p0, q1 → p3 * Sqrt[1 - z^2], q2 → 0, q3 → p3 * z,
     j0 → p3, j1 → -p3 * Sqrt[1 - z^2], j2 → 0,
     j3 → -p3 * z, p0 → (s + m^2) / (2 Sqrt[s]),
     p3 → (s - m^2) / (2 Sqrt[s]), z → 1 + t / (2 p3^2),
     t → 2 m^2 - s - u}, TimeConstraint → 5000];
T200 = Simplify[y200 / ((m256 / m) ^8) //.
    {p1 → 0, p2 → 0, k0 → p3, k1 → 0, k2 → 0, k3 → -p3,
     q0 → p0, q1 → p3 * Sqrt[1 - z^2], q2 → 0, q3 → p3 * z,
     j0 → p3, j1 → -p3 * Sqrt[1 - z^2], j2 → 0,
     j3 → -p3 * z, p0 → (s + m^2) / (2 Sqrt[s]),
     p3 → (s - m^2) / (2 Sqrt[s]), z → 1 + t / (2 p3^2),
     t → 2 m^2 - s - u}, TimeConstraint → 5000];
T300 = Simplify[y300 / ((m256 / m) ^8) //.
    {p1 → 0, p2 → 0, k0 → p3, k1 → 0, k2 → 0, k3 → -p3,
     q0 → p0, q1 → p3 * Sqrt[1 - z^2], q2 → 0, q3 → p3 * z,
     j0 → p3, j1 → -p3 * Sqrt[1 - z^2], j2 → 0,
     j3 → -p3 * z, p0 → (s + m^2) / (2 Sqrt[s]),
     p3 → (s - m^2) / (2 Sqrt[s]), z → 1 + t / (2 p3^2),
     t → 2 m^2 - s - u}, TimeConstraint → 5000];
T400 = Simplify[y400 / ((m256 / m) ^8) //.
    {p1 → 0, p2 → 0, k0 → p3, k1 → 0, k2 → 0, k3 → -p3,
     q0 → p0, q1 → p3 * Sqrt[1 - z^2], q2 → 0, q3 → p3 * z,
     j0 → p3, j1 → -p3 * Sqrt[1 - z^2], j2 → 0,
     j3 → -p3 * z, p0 → (s + m^2) / (2 Sqrt[s]),
     p3 → (s - m^2) / (2 Sqrt[s]), z → 1 + t / (2 p3^2),
```

```
    t → 2 m^2 - s - u}, TimeConstraint → 5000];


Print["f(s,u) ; ", T100];
Print["g(s,u) ; ", T200];
Print["f(u,s) ; ", T300];
Print["g(u,s) ; ", T400];


T500 = (m^2 / (s - m^2) ^2) *
   (1 * (T100 * (1 / (s - m^2) ^2) +
       (T300 + T400) * (1 / ((s - m^2) * (u - m^2))) +
      T200 * (1 / (u - m^2) ^2)));
 T600 = Pi * T500 * dt;
T700 = FullSimplify[
   ExpandAll[
    T600 /. s → 2 * m * w0 + m^2 /. u → -2 * m * w + m^2 /.
     dt → (1 / Pi) * w^2]];
T800 =
  T700 /. Solve[(w0 - w) / (w0 * w) == 1 / m * (1 - Cos[theta]),
     m] // Simplify;
y100 = FullSimplify[
   T800 /. w → w0 * u / (u + w0 (1 - Cos[theta])) /. w0 → γ * u /.
    u → m];
y200 = y100 /. theta → kakudo /. γ → 0.173 /. kakudo → 0;
T900 = T800 / y200;
Print[
  "Scattering cross section in a laboratory system
    (trial calculation example using 16 γ
    matrices (256*256) for curved space) ; ", T900];
γ = 0.173;
y300 = y100 / y200;
Print["γ=0.173 ; ", y300];
```

```
Print[
  "**************************************************
    **************************************************
    "];

Print[
  Style[
   "3.When using four γ matrices under Minkowski
     spacetime (conventional calculation) and
     γ matrix (256*256)\ under curved spacetime.
Comparison of trial calculation examples using
     16 (trial calculation examples in this paper)",
   Blue]];
Print["γ=0.173"];

Plot[{y30, y300}, {theta, 0, Pi},
 PlotStyle → {{Red, Dashed}, Blue}, AspectRatio → 0.75,
 Frame → True,
 PlotRange → {Degree * {0, 180}, {0, 1}},
 PlotLegends →
  Placed[LineLegend[Automatic,
    {"Conventional calculation",
     "Example of calculation for this paper"},
    LabelStyle → 8,
    LegendFunction →
     (Framed[#, Background → Opacity[4 / 4, White]] &),
    LegendLayout → "Column"], {{0.987, 0.955}, {1, 0.9}}],
 FrameLabel →
  {"Θ", dΦ / Labeled[dΩ, Subsuperscript["γ", 0, 2], Left]},
 FrameTicks →
  {{Table[{t, PaddedForm[t, {4, 2}]}, {t, 0, 1, 0.25}],
    None}, {Degree * Table[t, {t, 0, 180, 30}], None}},
 GridLines → {Degree * Table[t, {t, 0, 180, 30}],
   Table[t, {t, 0, 1, 0.25}]}]
```

Example of Compton scattering calculation

****

1.Compton scattering calculation using 4 γ matrices (4*4) (conventional calculation)

$f(s,u)$; $8 \left(m^4 - s\,u + m^2\,(3\,s + u)\right)$

$g(s,u)$; $8 \left(m^4 - s\,u + m^2\,(s + 3\,u)\right)$

$f(u,s)$; $8\,m^2 \left(2\,m^2 + s + u\right)$

$g(u,s)$; $8\,m^2 \left(2\,m^2 + s + u\right)$

Scattering cross section of laboratory system (conventional calculation) ;

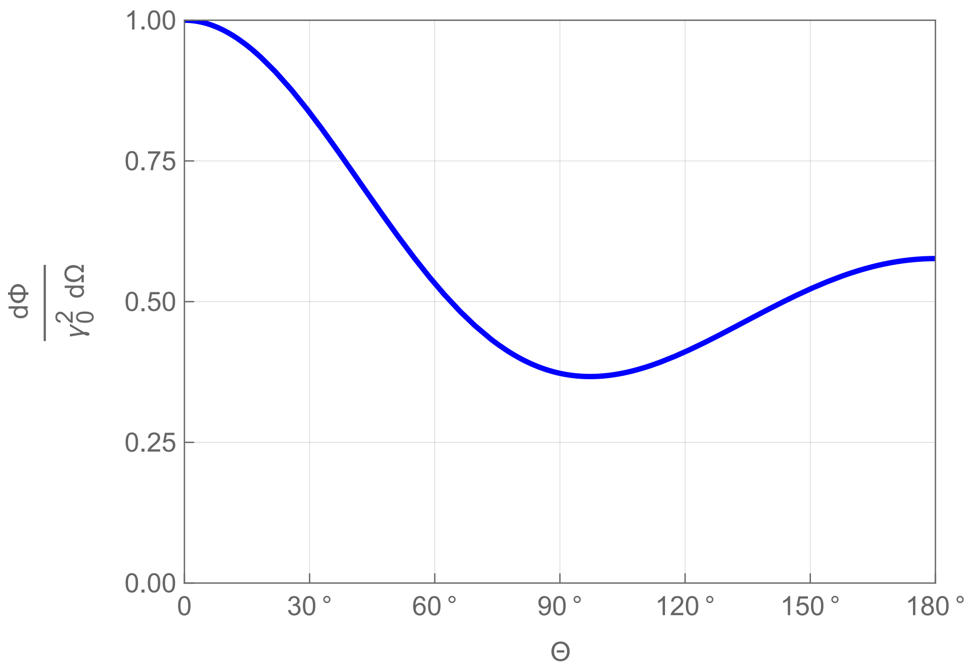
$$\left\{\frac{0.25\,w\left(2\,w^2 - w\,w0 + 2\,w0^2 + w\,w0\,\mathrm{Cos}[2\,\mathrm{theta}]\right)}{w0^3}\right\}$$

γ=0.173 ;

$$\left\{(0.125\,(1.45043\,\mathrm{Cos}[\mathrm{theta}] - 2.40586\,(3 + \mathrm{Cos}[2\,\mathrm{theta}]) + 0.173\,\mathrm{Cos}[3\,\mathrm{theta}]))\,/\,(-1.173 + 0.173\,\mathrm{Cos}[\mathrm{theta}])^3\right\}$$

γ=0.173

Out[∘]=



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****

2.Compton scattering calculation using γ matrix (256*256)

2.1.Calculation using 4 γ matrices (256*256) under Minkowski spacetime

Calculate the metric tensor as $\begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$

det (determinant of the metric tensor) = −1

f(s,u) ; $512\left(m^4 - s\,u + m^2\,(3\,s + u)\right)$

g(s,u) ; $512\left(m^4 - s\,u + m^2\,(s + 3\,u)\right)$

f(u,s) ; $512\,m^2\left(2\,m^2 + s + u\right)$

g(u,s) ; $512\,m^2\left(2\,m^2 + s + u\right)$

Scattering cross section of laboratory system (consistent with conventional calculation results) ;

$$\left\{\frac{0.25\,w\left(2\,w^2 - w\,w0 + 2\,w0^2 + w\,w0\,\mathrm{Cos}[2\,\mathrm{theta}]\right)}{w0^3}\right\}$$

Same as above (when γ=0.173) ;

$$\{(0.125\,(1.45043\,\mathrm{Cos}[\mathrm{theta}]-2.40586\,(3+\mathrm{Cos}[2\,\mathrm{theta}])+0.173\,\mathrm{Cos}[3\,\mathrm{theta}]))\,/\,(-1.173+0.173\,\mathrm{Cos}[\mathrm{theta}])^3\}$$

****

2.2.Trial calculation example using 16 γ matrices (256*256) in curved space-time

Calculate the metric tensor as $\begin{pmatrix} -1 & \frac{1}{999} & \frac{1}{999} & \frac{1}{999} \\ \frac{1}{999} & \frac{1000}{999} & \frac{1}{999} & \frac{1}{999} \\ \frac{1}{999} & \frac{1}{999} & \frac{1000}{999} & \frac{1}{999} \\ \frac{1}{999} & \frac{1}{999} & \frac{1}{999} & \frac{1000}{999} \end{pmatrix}$

det (determinant of the metric tensor) $=-\frac{333\,667}{332\,667}$

f(s,u) ;

$$((7\,980\,007\,911\,802\,121\,000\,000\,m^6+8\,023\,980\,511\,427\,065\,864\,560\,121\,m^4\,s+998\,001\,s^2\,(7\,980\,007\,911\,802\,121\,s-7\,984\,111\,896\,338\,000\,000\,u)+2\,m^2\,s\,(11\,924\,209\,592\,616\,455\,593\,060\,121\,s+3\,992\,055\,948\,169\,000\,000\,000\,000\,u))\,/\,(15\,625\,000\,000\,000\,000\,000\,000\,s))$$

g(s,u) ;

$$((15\,952\,068\,136\,315\,560\,121\,m^8-119\,700\,567\,320\,357\,143\,879\,758\,m^6\,s-7\,992\,091\,904\,249\,802\,121\,000\,000\,s^3\,u+1\,000\,000\,m^2\,s^2\,(7\,992\,091\,904\,249\,802\,121\,s+23\,968\,119\,752\,553\,268\,330\,u)+m^4\,s\,(8\,047\,920\,759\,019\,647\,647\,560\,121\,s+7\,948\,103\,807\,850\,113\,000\,000\,u))\,/\,(15\,625\,000\,000\,000\,000\,000\,000\,s^2))$$

f(u,s) ;

$$((-39\,916\,304\,183\,972\,593\,384\,143\,m^6+15\,824\,239\,447\,735\,098\,191\,231\,714\,m^4\,s-103\,784\,361\,508\,242\,000\,000\,s^2\,u+m^2\,s\,(7\,992\,107\,975\,706\,243\,354\,615\,857\,s+8\,032\,024\,279\,890\,215\,948\,000\,000\,u))\,/\,(15\,625\,000\,000\,000\,000\,000\,000\,s))$$

g(u,s) ;

$$\left(\left(-39\,916\,304\,183\,972\,593\,384\,143\,m^6 + 15\,824\,239\,447\,735\,098\,191\,231\,714\,m^4\,s - 103\,784\,361\,508\,242\,000\,000\,s^2\,u + m^2\,s\,(7\,992\,107\,975\,706\,243\,354\,615\,857\,s + 8\,032\,024\,279\,890\,215\,948\,000\,000\,u)\right) \Big/ (15\,625\,000\,000\,000\,000\,000\,000\,s)\right)$$

Scattering cross section in a laboratory system (trial calculation example using 16 γ matrices (256*256) for curved space) ;

$$\left\{\frac{1}{w0^3\left(2+\frac{w\,(-1+\mathrm{Cos}[\mathrm{theta}])}{w-w0}\right)^2} 5.69504\times 10^{-26}\,w\left(4\,(7\,968\,151\,656\,657\,220\,338\,000\,000\,w^2 + 7\,756\,487\,152\,969\,944\,560\,121\,w\,w0 + 7\,992\,091\,904\,249\,802\,121\,000\,000\,w0^2) + \frac{1}{w-w0}4\,w\,(7\,960\,171\,536\,816\,830\,507\,000\,000\,w^2 + 15\,987\,774\,802\,845\,509\,503\,180\,363\,w\,w0 - 7\,987\,926\,211\,246\,666\,096\,115\,857\,w0^2)\,(-1+\mathrm{Cos}[\mathrm{theta}]) + \frac{1}{(w-w0)^2}w\,(7\,936\,231\,177\,295\,661\,014\,000\,000\,w^3 + 95\,824\,153\,742\,139\,871\,320\,281\,573\,w^2\,w0 - 119\,632\,464\,499\,484\,019\,364\,158\,570\,w\,w0^2 + 32\,016\,040\,511\,572\,915\,977\,560\,121\,w0^3)\,(-1+\mathrm{Cos}[\mathrm{theta}])^2 + \frac{1}{(w-w0)^3}w^2\,(-7\,980\,119\,840\,389\,831\,000\,000\,w^3 + 47\,880\,332\,311\,865\,183\,760\,360\,726\,w^2\,w0 - 79\,640\,611\,701\,156\,519\,183\,926\,856\,w\,w0^2 + 31\,960\,164\,279\,816\,662\,462\,120\,242\,w0^3)\,(-1+\mathrm{Cos}[\mathrm{theta}])^3 + \frac{1}{(w-w0)^4}3\,w^3\,w0\,(2\,658\,692\,000\,010\,712\,105\,186\,707\,w^2 - 5\,301\,391\,935\,797\,679\,443\,077\,238\,w\,w0 + 2\,658\,692\,000\,010\,712\,105\,186\,707\,w0^2)\,(-1+\mathrm{Cos}[\mathrm{theta}])^4\right)\right\}$$

γ=0.173;

$$\left\{1.90285\times10^{-24}\left(7.98326\times10^{24}+\frac{1.07403\times10^{25}}{(1.173-0.173\,\mathrm{Cos}[\mathrm{theta}])^{2}}-\frac{2.37098\times10^{23}}{(-1.173+0.173\,\mathrm{Cos}[\mathrm{theta}])^{3}}+\frac{1.84352\times10^{25}}{-1.173+0.173\,\mathrm{Cos}[\mathrm{theta}]}\right)\right\}$$

****

3.When using four γ matrices under Minkowski spacetime (conventional calculation) and γ matrix (256*256) under curved spacetime.
Comparison of trial calculation examples using 16 (trial calculation examples in this paper)

γ=0.173

Out[∘]=