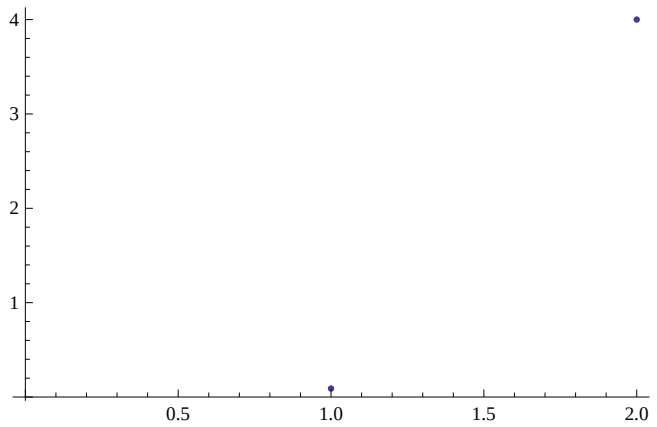
In[1]:=
```
f[γ_] = ((1 + γ) / 8) (Pi / 2 - ArcSin[1 / (Sqrt[1 + γ])]) - Sqrt[γ] / 8;
F[γ_, k_, a_] = ((f[γ] - γ * D[f[γ], γ]) / ((1 + γ) * D[f[γ], γ] - f[γ]))
    ((1 + (2^7 k^2 * (D[f[γ], γ])^2) / (a^2)) / (2^7 k^2 * (D[f[γ], γ])^2));
γT[ω_, k_, a_] = -1 + 1 / (Cos[ω / (Sqrt[2] * k^2 * Sqrt[1 - ω^2 / (k^2 * a^2)])])^2;
ωT[γ_, k_, a_] = (Sqrt[2] * k^2 * ((Pi / 2) - ArcSin[1 / Sqrt[1 + γ]])) /
    Sqrt[1 + (2 * k^2 * ((Pi / 2) - ArcSin[1 / Sqrt[1 + γ]])^2) / a^2];
Fω[γ_, k_, a_] = D[F[γ, k, a], γ] / D[ωT[γ, k, a], γ];
Fωω[γ_, k_, a_] = D[F[γ, k, a], γ, γ] / (D[ωT[γ, k, a], γ])^2 -
    D[F[γ, k, a], γ] * D[ωT[γ, k, a], γ, γ] / (D[ωT[γ, k, a], γ])^3;
Fk[γ_, k_, a_] = D[F[γ, k, a], k] - D[F[γ, k, a], γ] * D[ωT[γ, k, a], k] / D[ωT[γ, k, a], γ];
Fkk[γ_, k_, a_] =
  D[F[γ, k, a], k, k] - 2 * D[F[γ, k, a], γ, k] * D[ωT[γ, k, a], k] / D[ωT[γ, k, a], γ] +
    D[F[γ, k, a], γ, γ] * (D[ωT[γ, k, a], k] / D[ωT[γ, k, a], γ])^2 -
    D[F[γ, k, a], γ] * (D[ωT[γ, k, a], k, k] * D[ωT[γ, k, a], γ] +
        D[ωT[γ, k, a], γ, γ] * (D[ωT[γ, k, a], k]^2) / D[ωT[γ, k, a], γ] -
        2 * D[ωT[γ, k, a], k] * D[ωT[γ, k, a], γ, k]) / (D[ωT[γ, k, a], γ])^2;
Fωk[γ_, k_, a_] = D[F[γ, k, a], γ, k] / D[ωT[γ, k, a], γ] -
    D[F[γ, k, a], γ, γ] / (D[ωT[γ, k, a], γ])^2 * D[ωT[γ, k, a], k] -
    D[F[γ, k, a], γ] * (D[ωT[γ, k, a], γ, k] * D[ωT[γ, k, a], γ] -
        D[ωT[γ, k, a], γ, γ] * D[ωT[γ, k, a], k]) / (D[ωT[γ, k, a], γ])^3;
P4[γ_, k_, a_, λ_] = (F[γ, k, a] * Fωω[γ, k, a] - 2 * (Fω[γ, k, a])^2) * λ^4 +
    2 (F[γ, k, a] * Fωk[γ, k, a] - 2 * Fω[γ, k, a] * Fk[γ, k, a]) * λ^3 +
    (Fωω[γ, k, a] + F[γ, k, a] * Fkk[γ, k, a] - 2 * (Fk[γ, k, a])^2) * λ^2 +
    2 * Fωk[γ, k, a] * λ + Fkk[γ, k, a];
```

In[11]:=
```
G[λ_] = λ;
a = 0.1;
For[k = 0, k < 1,
 For[γ = 0, γ < 10,
  {sol = NSolve[P4[γ, k, a, λ] == 0, λ],
   W = G[λ] /. sol[[1]];
   X = G[λ] /. sol[[2]];
   Y = G[λ] /. sol[[3]];
   Z = G[λ] /. sol[[4]];
   If[Im[W] == 0 && Im[X] == 0 && Im[Y] == 0 && Im[Z] == 0,
    {Print[k], Print[γ]; Print[ListPlot[{k, γ}]]}]}, γ = γ + 1], k = k + 0.01]
```

```
0.09

4
```

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0.09

5
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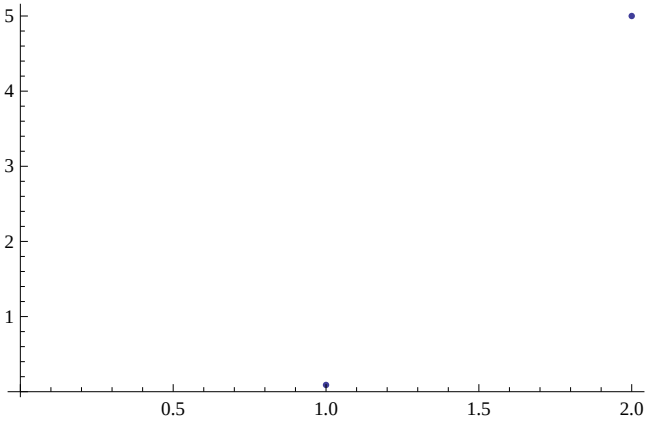

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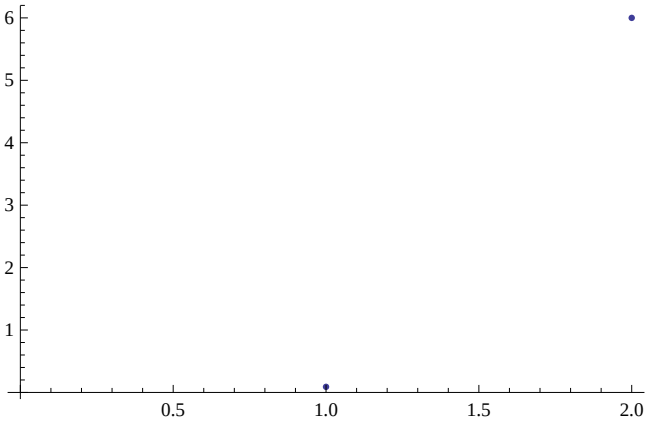
6



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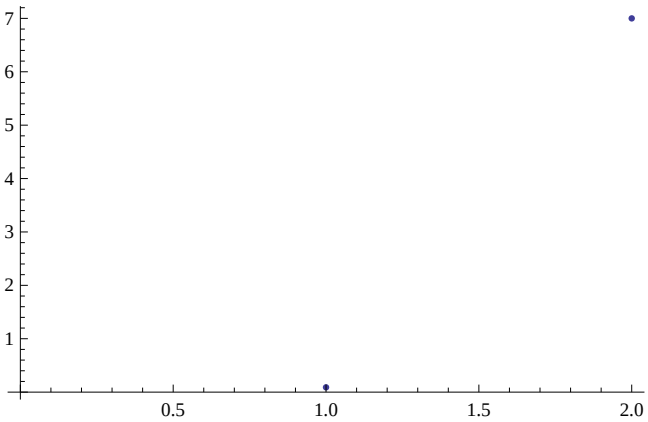

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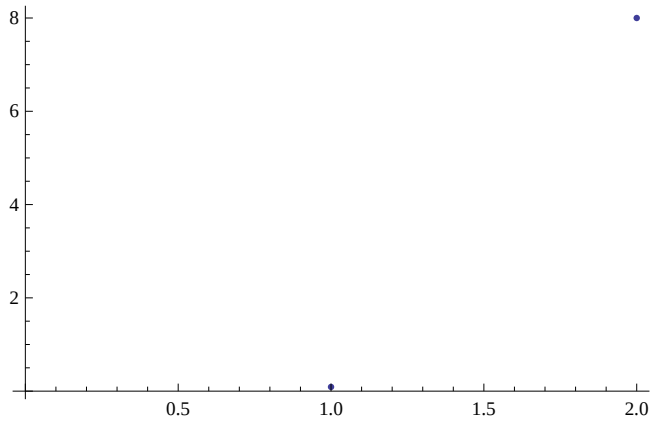

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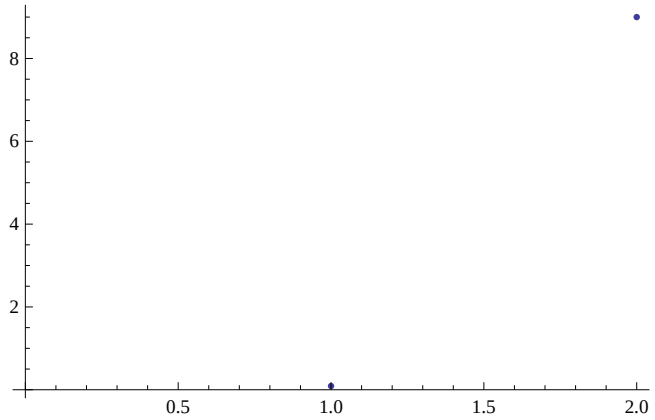

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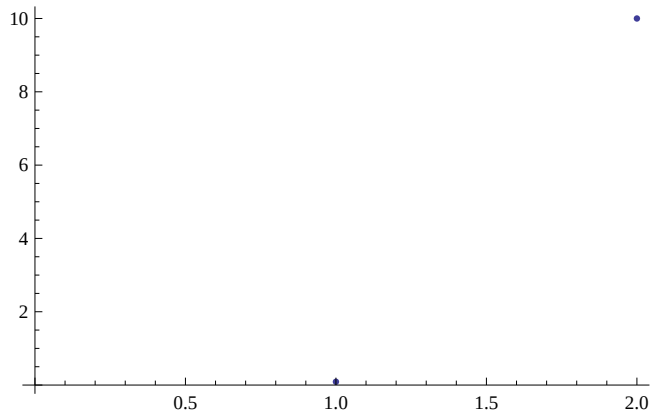
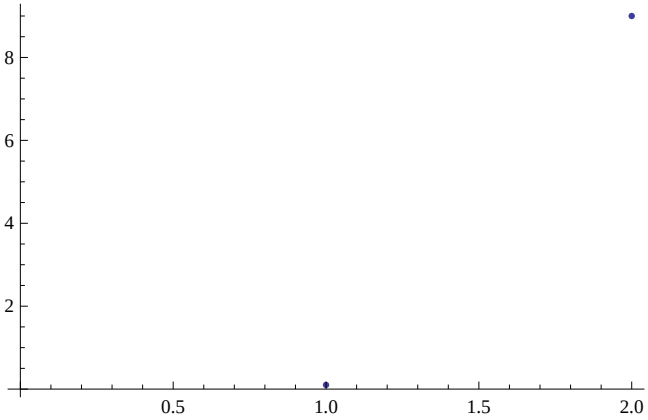
10



0.1

9

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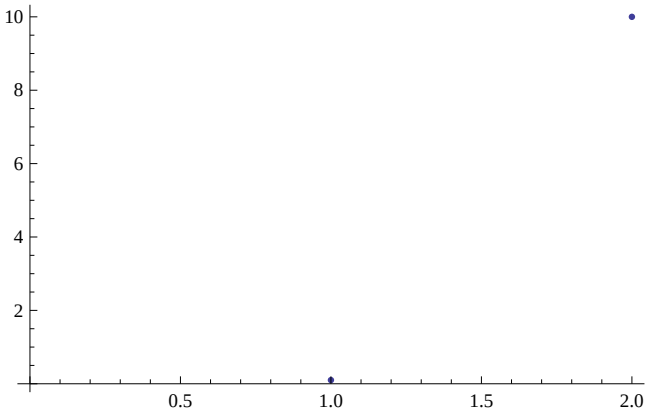
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10
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