5/4/2021 Milind Diwan

Calculate the Inverse Beta Decay cross section. We use the formulas from
P. Vogel and J. F. Beacom, Phys. Rev. D 60, 053003.

This is good only up to 20 MeV. For higher energies, we need to get other formulas.

There are two functions:
CrossSection0 is a simple 0th order calculation.

CrossSection1 is a calculation that is made by integrating the differential cross section from the paper.
In this function, I have included an explicit dependence on the lifetime of the neutron and the Ga constant.

The function is called to produce a table of cross section. This can be used for subsequent rate calculations using interpolation.

In[•]:=

```
(* calculate the 0th order cross section for comparison *)
CrossSection0[Enu_] :=
  Module[{Mproton, Mneutron, Melectron, Ethres, Delta, Ee, Pe, Cross},
   Mproton = 938.27203;
   Mneutron = 939.56536;
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```
    Melectron = 0.51099892;
    Delta = Mneutron - Mproton;
    Ethres = 1.806;
    Ee = Enu - Delta;
    Pe = Sqrt[Ee^2 - Melectron^2];
    If[Enu < Ethres, Cross = 0,
     Cross = 0.0952 * Ee * Pe * 10^-42]; (* cm^2 *)
    Return[Cross]];

(*calculate the 1st order cross section using
 the integral over differential cross section *)
CrossSection1[Enu_, Tneutron_, ga_] :=
  Module[{sigma0, sigma0Old, f, g, f2, nu0, Mproton, Mneutron, Melectron, Ethres,
    Delta, Ee, Pe, costh, Cross, t, TneutronNew, TneutronOld, sigma0C, gaNew},
   f = 1; g = ga;
   f2 = 3.705890;
   sigma0C = 0.0164462; (* this is in units of 10^-42 cm^2/MeV^2 *)
   TneutronNew = 881.5;
   gaNew = 1.2701;
   sigma0 = sigma0C * (TneutronNew / Tneutron) * ((1 + 3 * gaNew^2) / (f^2 + 3 * g^2));

   Mproton = 938.27203;
   Mneutron = 939.56536;
   Melectron = 0.51099892;
   Delta = Mneutron - Mproton;
   Ethres = 1.806;
   Ee = Enu - Delta;
   Pe = Sqrt[Ee^2 - Melectron^2];
   dSdC[x_] :=
    Module[{Ee1, Pe1, v0, v1, y2, Value, BigL1, BigL2, BigL3, BigL4, BigL},
     v0 = Pe / Ee;
     y2 = (Delta^2 - Melectron^2) / 2;
     Ee1 = Ee * (1 - (Enu / Mproton) * (1 - v0 * x)) - y2 / Mproton;
     Pe1 = Sqrt[Ee1^2 - Melectron^2];
     v1 = Pe1 / Ee1;
     BigL1 = 2 * (f + f2) * g ((2 * Ee + Delta) * (1 - v0 * x) - Melectron^2 / Ee);
     BigL2 = (f^2 + g^2) * (Delta * (1 + v0 * x) + Melectron^2 / Ee);
     BigL3 = (f^2 + 3 * g^2) * ((Ee + Delta) * (1 - (1 / v0) * x) - Delta);
     BigL4 = (f^2 - g^2) * ((Ee + Delta) * (1 - (1 / v0) * x) - Delta) * v0 * x;
     BigL = BigL1 + BigL2 + BigL3 + BigL4;
     Value = (sigma0 / 2) * ((f^2 + 3 * g^2) + (f^2 - g^2) * v1 * x) * Ee1 * Pe1 -
       (sigma0 / 2) * (BigL / Mproton) * Ee * Pe;
     (*Value = (sigma0/2)*(BigL/Mproton)*Ee*Pe;*)
```

```
    Return[Value]];
  If[Enu < Ethres, Cross = 0,
   Cross = Sum[
     dSdC[t] * 0.002 + 0.5 * (dSdC[t + 0.002] - dSdC[t]) * 0.002, {t, -1, 1, 0.002}]];
  Return[Cross * 10^-42]];


Ctabulate = Table[{x, CrossSection1[x, 881.5, 1.2701]}, {x, 0, 20, 0.01}];
Cross1FromTable = Interpolation[Ctabulate];
Print[Ctabulate];
```

```
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$$\{4.98, 1.25036\times10^{-42}\}, \{4.99, 1.25713\times10^{-42}\}, \{5., 1.2639\times10^{-42}\}, \{5.01, 1.2707\times10^{-42}\},$$
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$$\{5.1, 1.33265\times10^{-42}\}, \{5.11, 1.33962\times10^{-42}\}, \{5.12, 1.34661\times10^{-42}\}, \{5.13, 1.35361\times10^{-42}\},$$
$$\{5.14, 1.36064\times10^{-42}\}, \{5.15, 1.36768\times10^{-42}\}, \{5.16, 1.37473\times10^{-42}\}, \{5.17, 1.38181\times10^{-42}\},$$
$$\{5.18, 1.3889\times10^{-42}\}, \{5.19, 1.39601\times10^{-42}\}, \{5.2, 1.40314\times10^{-42}\}, \{5.21, 1.41028\times10^{-42}\},$$
$$\{5.22, 1.41745\times10^{-42}\}, \{5.23, 1.42463\times10^{-42}\}, \{5.24, 1.43182\times10^{-42}\}, \{5.25, 1.43904\times10^{-42}\},$$
$$\{5.26, 1.44627\times10^{-42}\}, \{5.27, 1.45352\times10^{-42}\}, \{5.28, 1.46078\times10^{-42}\}, \{5.29, 1.46807\times10^{-42}\},$$
$$\{5.3, 1.47537\times10^{-42}\}, \{5.31, 1.48269\times10^{-42}\}, \{5.32, 1.49002\times10^{-42}\}, \{5.33, 1.49738\times10^{-42}\},$$
$$\{5.34, 1.50475\times10^{-42}\}, \{5.35, 1.51214\times10^{-42}\}, \{5.36, 1.51954\times10^{-42}\}, \{5.37, 1.52696\times10^{-42}\},$$
$$\{5.38, 1.5344\times10^{-42}\}, \{5.39, 1.54186\times10^{-42}\}, \{5.4, 1.54933\times10^{-42}\}, \{5.41, 1.55683\times10^{-42}\},$$
$$\{5.42, 1.56434\times10^{-42}\}, \{5.43, 1.57186\times10^{-42}\}, \{5.44, 1.57941\times10^{-42}\}, \{5.45, 1.58697\times10^{-42}\},$$
$$\{5.46, 1.59455\times10^{-42}\}, \{5.47, 1.60214\times10^{-42}\}, \{5.48, 1.60975\times10^{-42}\}, \{5.49, 1.61738\times10^{-42}\},$$
$$\{5.5, 1.62503\times10^{-42}\}, \{5.51, 1.6327\times10^{-42}\}, \{5.52, 1.64038\times10^{-42}\}, \{5.53, 1.64808\times10^{-42}\},$$
$$\{5.54, 1.65579\times10^{-42}\}, \{5.55, 1.66353\times10^{-42}\}, \{5.56, 1.67128\times10^{-42}\}, \{5.57, 1.67905\times10^{-42}\},$$
$$\{5.58, 1.68683\times10^{-42}\}, \{5.59, 1.69464\times10^{-42}\}, \{5.6, 1.70246\times10^{-42}\}, \{5.61, 1.71029\times10^{-42}\},$$
$$\{5.62, 1.71815\times10^{-42}\}, \{5.63, 1.72602\times10^{-42}\}, \{5.64, 1.73391\times10^{-42}\}, \{5.65, 1.74182\times10^{-42}\},$$
$$\{5.66, 1.74974\times10^{-42}\}, \{5.67, 1.75768\times10^{-42}\}, \{5.68, 1.76564\times10^{-42}\}, \{5.69, 1.77361\times10^{-42}\},$$
$$\{5.7, 1.7816\times10^{-42}\}, \{5.71, 1.78961\times10^{-42}\}, \{5.72, 1.79764\times10^{-42}\}, \{5.73, 1.80568\times10^{-42}\},$$
$$\{5.74, 1.81374\times10^{-42}\}, \{5.75, 1.82182\times10^{-42}\}, \{5.76, 1.82992\times10^{-42}\}, \{5.77, 1.83803\times10^{-42}\},$$
$$\{5.78, 1.84616\times10^{-42}\}, \{5.79, 1.85431\times10^{-42}\}, \{5.8, 1.86247\times10^{-42}\}, \{5.81, 1.87065\times10^{-42}\},$$
$$\{5.82, 1.87885\times10^{-42}\}, \{5.83, 1.88706\times10^{-42}\}, \{5.84, 1.8953\times10^{-42}\}, \{5.85, 1.90355\times10^{-42}\},$$
$$\{5.86, 1.91181\times10^{-42}\}, \{5.87, 1.9201\times10^{-42}\}, \{5.88, 1.9284\times10^{-42}\}, \{5.89, 1.93671\times10^{-42}\},$$
$$\{5.9, 1.94505\times10^{-42}\}, \{5.91, 1.9534\times10^{-42}\}, \{5.92, 1.96177\times10^{-42}\}, \{5.93, 1.97016\times10^{-42}\},$$

$$\{5.94, 1.97856\times10^{-42}\}, \{5.95, 1.98698\times10^{-42}\}, \{5.96, 1.99542\times10^{-42}\}, \{5.97, 2.00387\times10^{-42}\},$$
$$\{5.98, 2.01234\times10^{-42}\}, \{5.99, 2.02083\times10^{-42}\}, \{6., 2.02934\times10^{-42}\}, \{6.01, 2.03786\times10^{-42}\},$$
$$\{6.02, 2.0464\times10^{-42}\}, \{6.03, 2.05496\times10^{-42}\}, \{6.04, 2.06353\times10^{-42}\}, \{6.05, 2.07212\times10^{-42}\},$$
$$\{6.06, 2.08073\times10^{-42}\}, \{6.07, 2.08936\times10^{-42}\}, \{6.08, 2.098\times10^{-42}\}, \{6.09, 2.10666\times10^{-42}\},$$
$$\{6.1, 2.11533\times10^{-42}\}, \{6.11, 2.12403\times10^{-42}\}, \{6.12, 2.13274\times10^{-42}\}, \{6.13, 2.14146\times10^{-42}\},$$
$$\{6.14, 2.15021\times10^{-42}\}, \{6.15, 2.15897\times10^{-42}\}, \{6.16, 2.16775\times10^{-42}\}, \{6.17, 2.17654\times10^{-42}\},$$
$$\{6.18, 2.18535\times10^{-42}\}, \{6.19, 2.19418\times10^{-42}\}, \{6.2, 2.20303\times10^{-42}\}, \{6.21, 2.21189\times10^{-42}\},$$
$$\{6.22, 2.22077\times10^{-42}\}, \{6.23, 2.22967\times10^{-42}\}, \{6.24, 2.23858\times10^{-42}\}, \{6.25, 2.24751\times10^{-42}\},$$
$$\{6.26, 2.25646\times10^{-42}\}, \{6.27, 2.26542\times10^{-42}\}, \{6.28, 2.27441\times10^{-42}\}, \{6.29, 2.2834\times10^{-42}\},$$
$$\{6.3, 2.29242\times10^{-42}\}, \{6.31, 2.30145\times10^{-42}\}, \{6.32, 2.3105\times10^{-42}\}, \{6.33, 2.31957\times10^{-42}\},$$
$$\{6.34, 2.32865\times10^{-42}\}, \{6.35, 2.33775\times10^{-42}\}, \{6.36, 2.34687\times10^{-42}\}, \{6.37, 2.356\times10^{-42}\},$$
$$\{6.38, 2.36515\times10^{-42}\}, \{6.39, 2.37432\times10^{-42}\}, \{6.4, 2.3835\times10^{-42}\}, \{6.41, 2.3927\times10^{-42}\},$$
$$\{6.42, 2.40192\times10^{-42}\}, \{6.43, 2.41116\times10^{-42}\}, \{6.44, 2.42041\times10^{-42}\}, \{6.45, 2.42968\times10^{-42}\},$$
$$\{6.46, 2.43896\times10^{-42}\}, \{6.47, 2.44827\times10^{-42}\}, \{6.48, 2.45759\times10^{-42}\}, \{6.49, 2.46692\times10^{-42}\},$$
$$\{6.5, 2.47627\times10^{-42}\}, \{6.51, 2.48564\times10^{-42}\}, \{6.52, 2.49503\times10^{-42}\}, \{6.53, 2.50443\times10^{-42}\},$$
$$\{6.54, 2.51385\times10^{-42}\}, \{6.55, 2.52329\times10^{-42}\}, \{6.56, 2.53275\times10^{-42}\}, \{6.57, 2.54222\times10^{-42}\},$$
$$\{6.58, 2.5517\times10^{-42}\}, \{6.59, 2.56121\times10^{-42}\}, \{6.6, 2.57073\times10^{-42}\}, \{6.61, 2.58027\times10^{-42}\},$$
$$\{6.62, 2.58982\times10^{-42}\}, \{6.63, 2.59939\times10^{-42}\}, \{6.64, 2.60898\times10^{-42}\}, \{6.65, 2.61859\times10^{-42}\},$$
$$\{6.66, 2.62821\times10^{-42}\}, \{6.67, 2.63785\times10^{-42}\}, \{6.68, 2.6475\times10^{-42}\}, \{6.69, 2.65717\times10^{-42}\},$$
$$\{6.7, 2.66686\times10^{-42}\}, \{6.71, 2.67657\times10^{-42}\}, \{6.72, 2.68629\times10^{-42}\}, \{6.73, 2.69603\times10^{-42}\},$$
$$\{6.74, 2.70578\times10^{-42}\}, \{6.75, 2.71556\times10^{-42}\}, \{6.76, 2.72535\times10^{-42}\}, \{6.77, 2.73515\times10^{-42}\},$$
$$\{6.78, 2.74497\times10^{-42}\}, \{6.79, 2.75481\times10^{-42}\}, \{6.8, 2.76467\times10^{-42}\}, \{6.81, 2.77454\times10^{-42}\},$$
$$\{6.82, 2.78443\times10^{-42}\}, \{6.83, 2.79434\times10^{-42}\}, \{6.84, 2.80426\times10^{-42}\}, \{6.85, 2.8142\times10^{-42}\},$$
$$\{6.86, 2.82416\times10^{-42}\}, \{6.87, 2.83413\times10^{-42}\}, \{6.88, 2.84412\times10^{-42}\}, \{6.89, 2.85413\times10^{-42}\},$$
$$\{6.9, 2.86415\times10^{-42}\}, \{6.91, 2.87419\times10^{-42}\}, \{6.92, 2.88424\times10^{-42}\}, \{6.93, 2.89432\times10^{-42}\},$$
$$\{6.94, 2.90441\times10^{-42}\}, \{6.95, 2.91451\times10^{-42}\}, \{6.96, 2.92463\times10^{-42}\}, \{6.97, 2.93477\times10^{-42}\},$$
$$\{6.98, 2.94493\times10^{-42}\}, \{6.99, 2.9551\times10^{-42}\}, \{7., 2.96529\times10^{-42}\}, \{7.01, 2.9755\times10^{-42}\},$$
$$\{7.02, 2.98572\times10^{-42}\}, \{7.03, 2.99596\times10^{-42}\}, \{7.04, 3.00621\times10^{-42}\}, \{7.05, 3.01649\times10^{-42}\},$$
$$\{7.06, 3.02678\times10^{-42}\}, \{7.07, 3.03708\times10^{-42}\}, \{7.08, 3.0474\times10^{-42}\}, \{7.09, 3.05774\times10^{-42}\},$$
$$\{7.1, 3.0681\times10^{-42}\}, \{7.11, 3.07847\times10^{-42}\}, \{7.12, 3.08886\times10^{-42}\}, \{7.13, 3.09926\times10^{-42}\},$$
$$\{7.14, 3.10968\times10^{-42}\}, \{7.15, 3.12012\times10^{-42}\}, \{7.16, 3.13057\times10^{-42}\}, \{7.17, 3.14105\times10^{-42}\},$$
$$\{7.18, 3.15153\times10^{-42}\}, \{7.19, 3.16204\times10^{-42}\}, \{7.2, 3.17256\times10^{-42}\}, \{7.21, 3.18309\times10^{-42}\},$$
$$\{7.22, 3.19365\times10^{-42}\}, \{7.23, 3.20422\times10^{-42}\}, \{7.24, 3.21481\times10^{-42}\}, \{7.25, 3.22541\times10^{-42}\},$$
$$\{7.26, 3.23603\times10^{-42}\}, \{7.27, 3.24666\times10^{-42}\}, \{7.28, 3.25732\times10^{-42}\}, \{7.29, 3.26799\times10^{-42}\},$$
$$\{7.3, 3.27867\times10^{-42}\}, \{7.31, 3.28937\times10^{-42}\}, \{7.32, 3.30009\times10^{-42}\}, \{7.33, 3.31083\times10^{-42}\},$$
$$\{7.34, 3.32158\times10^{-42}\}, \{7.35, 3.33235\times10^{-42}\}, \{7.36, 3.34313\times10^{-42}\}, \{7.37, 3.35393\times10^{-42}\},$$
$$\{7.38, 3.36475\times10^{-42}\}, \{7.39, 3.37558\times10^{-42}\}, \{7.4, 3.38643\times10^{-42}\}, \{7.41, 3.3973\times10^{-42}\},$$
$$\{7.42, 3.40818\times10^{-42}\}, \{7.43, 3.41908\times10^{-42}\}, \{7.44, 3.43\times10^{-42}\}, \{7.45, 3.44093\times10^{-42}\},$$
$$\{7.46, 3.45188\times10^{-42}\}, \{7.47, 3.46285\times10^{-42}\}, \{7.48, 3.47383\times10^{-42}\}, \{7.49, 3.48482\times10^{-42}\},$$
$$\{7.5, 3.49584\times10^{-42}\}, \{7.51, 3.50687\times10^{-42}\}, \{7.52, 3.51792\times10^{-42}\}, \{7.53, 3.52898\times10^{-42}\},$$
$$\{7.54, 3.54006\times10^{-42}\}, \{7.55, 3.55116\times10^{-42}\}, \{7.56, 3.56227\times10^{-42}\}, \{7.57, 3.5734\times10^{-42}\},$$
$$\{7.58, 3.58454\times10^{-42}\}, \{7.59, 3.59571\times10^{-42}\}, \{7.6, 3.60688\times10^{-42}\}, \{7.61, 3.61808\times10^{-42}\},$$
$$\{7.62, 3.62929\times10^{-42}\}, \{7.63, 3.64052\times10^{-42}\}, \{7.64, 3.65176\times10^{-42}\}, \{7.65, 3.66302\times10^{-42}\},$$
$$\{7.66, 3.6743\times10^{-42}\}, \{7.67, 3.68559\times10^{-42}\}, \{7.68, 3.6969\times10^{-42}\}, \{7.69, 3.70822\times10^{-42}\},$$
$$\{7.7, 3.71956\times10^{-42}\}, \{7.71, 3.73092\times10^{-42}\}, \{7.72, 3.7423\times10^{-42}\}, \{7.73, 3.75369\times10^{-42}\},$$

$$\{7.74, 3.76509\times10^{-42}\}, \{7.75, 3.77652\times10^{-42}\}, \{7.76, 3.78796\times10^{-42}\}, \{7.77, 3.79941\times10^{-42}\},$$
$$\{7.78, 3.81088\times10^{-42}\}, \{7.79, 3.82237\times10^{-42}\}, \{7.8, 3.83387\times10^{-42}\}, \{7.81, 3.8454\times10^{-42}\},$$
$$\{7.82, 3.85693\times10^{-42}\}, \{7.83, 3.86848\times10^{-42}\}, \{7.84, 3.88005\times10^{-42}\}, \{7.85, 3.89164\times10^{-42}\},$$
$$\{7.86, 3.90324\times10^{-42}\}, \{7.87, 3.91486\times10^{-42}\}, \{7.88, 3.92649\times10^{-42}\}, \{7.89, 3.93814\times10^{-42}\},$$
$$\{7.9, 3.94981\times10^{-42}\}, \{7.91, 3.96149\times10^{-42}\}, \{7.92, 3.97319\times10^{-42}\}, \{7.93, 3.98491\times10^{-42}\},$$
$$\{7.94, 3.99664\times10^{-42}\}, \{7.95, 4.00839\times10^{-42}\}, \{7.96, 4.02015\times10^{-42}\}, \{7.97, 4.03193\times10^{-42}\},$$
$$\{7.98, 4.04373\times10^{-42}\}, \{7.99, 4.05554\times10^{-42}\}, \{8., 4.06737\times10^{-42}\}, \{8.01, 4.07921\times10^{-42}\},$$
$$\{8.02, 4.09108\times10^{-42}\}, \{8.03, 4.10295\times10^{-42}\}, \{8.04, 4.11485\times10^{-42}\}, \{8.05, 4.12676\times10^{-42}\},$$
$$\{8.06, 4.13868\times10^{-42}\}, \{8.07, 4.15062\times10^{-42}\}, \{8.08, 4.16258\times10^{-42}\}, \{8.09, 4.17455\times10^{-42}\},$$
$$\{8.1, 4.18654\times10^{-42}\}, \{8.11, 4.19855\times10^{-42}\}, \{8.12, 4.21057\times10^{-42}\}, \{8.13, 4.22261\times10^{-42}\},$$
$$\{8.14, 4.23467\times10^{-42}\}, \{8.15, 4.24674\times10^{-42}\}, \{8.16, 4.25882\times10^{-42}\}, \{8.17, 4.27093\times10^{-42}\},$$
$$\{8.18, 4.28305\times10^{-42}\}, \{8.19, 4.29518\times10^{-42}\}, \{8.2, 4.30733\times10^{-42}\}, \{8.21, 4.3195\times10^{-42}\},$$
$$\{8.22, 4.33168\times10^{-42}\}, \{8.23, 4.34388\times10^{-42}\}, \{8.24, 4.3561\times10^{-42}\}, \{8.25, 4.36833\times10^{-42}\},$$
$$\{8.26, 4.38058\times10^{-42}\}, \{8.27, 4.39284\times10^{-42}\}, \{8.28, 4.40512\times10^{-42}\}, \{8.29, 4.41742\times10^{-42}\},$$
$$\{8.3, 4.42973\times10^{-42}\}, \{8.31, 4.44206\times10^{-42}\}, \{8.32, 4.4544\times10^{-42}\}, \{8.33, 4.46676\times10^{-42}\},$$
$$\{8.34, 4.47914\times10^{-42}\}, \{8.35, 4.49153\times10^{-42}\}, \{8.36, 4.50394\times10^{-42}\}, \{8.37, 4.51636\times10^{-42}\},$$
$$\{8.38, 4.5288\times10^{-42}\}, \{8.39, 4.54126\times10^{-42}\}, \{8.4, 4.55373\times10^{-42}\}, \{8.41, 4.56622\times10^{-42}\},$$
$$\{8.42, 4.57872\times10^{-42}\}, \{8.43, 4.59124\times10^{-42}\}, \{8.44, 4.60378\times10^{-42}\}, \{8.45, 4.61633\times10^{-42}\},$$
$$\{8.46, 4.6289\times10^{-42}\}, \{8.47, 4.64148\times10^{-42}\}, \{8.48, 4.65408\times10^{-42}\}, \{8.49, 4.6667\times10^{-42}\},$$
$$\{8.5, 4.67933\times10^{-42}\}, \{8.51, 4.69198\times10^{-42}\}, \{8.52, 4.70464\times10^{-42}\}, \{8.53, 4.71732\times10^{-42}\},$$
$$\{8.54, 4.73002\times10^{-42}\}, \{8.55, 4.74273\times10^{-42}\}, \{8.56, 4.75546\times10^{-42}\}, \{8.57, 4.7682\times10^{-42}\},$$
$$\{8.58, 4.78096\times10^{-42}\}, \{8.59, 4.79374\times10^{-42}\}, \{8.6, 4.80653\times10^{-42}\}, \{8.61, 4.81934\times10^{-42}\},$$
$$\{8.62, 4.83216\times10^{-42}\}, \{8.63, 4.845\times10^{-42}\}, \{8.64, 4.85785\times10^{-42}\}, \{8.65, 4.87072\times10^{-42}\},$$
$$\{8.66, 4.88361\times10^{-42}\}, \{8.67, 4.89651\times10^{-42}\}, \{8.68, 4.90943\times10^{-42}\}, \{8.69, 4.92236\times10^{-42}\},$$
$$\{8.7, 4.93532\times10^{-42}\}, \{8.71, 4.94828\times10^{-42}\}, \{8.72, 4.96126\times10^{-42}\}, \{8.73, 4.97426\times10^{-42}\},$$
$$\{8.74, 4.98727\times10^{-42}\}, \{8.75, 5.0003\times10^{-42}\}, \{8.76, 5.01335\times10^{-42}\}, \{8.77, 5.02641\times10^{-42}\},$$
$$\{8.78, 5.03949\times10^{-42}\}, \{8.79, 5.05258\times10^{-42}\}, \{8.8, 5.06569\times10^{-42}\}, \{8.81, 5.07881\times10^{-42}\},$$
$$\{8.82, 5.09195\times10^{-42}\}, \{8.83, 5.10511\times10^{-42}\}, \{8.84, 5.11828\times10^{-42}\}, \{8.85, 5.13147\times10^{-42}\},$$
$$\{8.86, 5.14467\times10^{-42}\}, \{8.87, 5.15789\times10^{-42}\}, \{8.88, 5.17113\times10^{-42}\}, \{8.89, 5.18438\times10^{-42}\},$$
$$\{8.9, 5.19764\times10^{-42}\}, \{8.91, 5.21093\times10^{-42}\}, \{8.92, 5.22423\times10^{-42}\}, \{8.93, 5.23754\times10^{-42}\},$$
$$\{8.94, 5.25087\times10^{-42}\}, \{8.95, 5.26421\times10^{-42}\}, \{8.96, 5.27758\times10^{-42}\}, \{8.97, 5.29095\times10^{-42}\},$$
$$\{8.98, 5.30435\times10^{-42}\}, \{8.99, 5.31775\times10^{-42}\}, \{9., 5.33118\times10^{-42}\}, \{9.01, 5.34462\times10^{-42}\},$$
$$\{9.02, 5.35807\times10^{-42}\}, \{9.03, 5.37155\times10^{-42}\}, \{9.04, 5.38503\times10^{-42}\}, \{9.05, 5.39854\times10^{-42}\},$$
$$\{9.06, 5.41205\times10^{-42}\}, \{9.07, 5.42559\times10^{-42}\}, \{9.08, 5.43914\times10^{-42}\}, \{9.09, 5.4527\times10^{-42}\},$$
$$\{9.1, 5.46629\times10^{-42}\}, \{9.11, 5.47988\times10^{-42}\}, \{9.12, 5.4935\times10^{-42}\}, \{9.13, 5.50712\times10^{-42}\},$$
$$\{9.14, 5.52077\times10^{-42}\}, \{9.15, 5.53443\times10^{-42}\}, \{9.16, 5.5481\times10^{-42}\}, \{9.17, 5.56179\times10^{-42}\},$$
$$\{9.18, 5.5755\times10^{-42}\}, \{9.19, 5.58922\times10^{-42}\}, \{9.2, 5.60296\times10^{-42}\}, \{9.21, 5.61672\times10^{-42}\},$$
$$\{9.22, 5.63048\times10^{-42}\}, \{9.23, 5.64427\times10^{-42}\}, \{9.24, 5.65807\times10^{-42}\}, \{9.25, 5.67189\times10^{-42}\},$$
$$\{9.26, 5.68572\times10^{-42}\}, \{9.27, 5.69957\times10^{-42}\}, \{9.28, 5.71343\times10^{-42}\}, \{9.29, 5.72731\times10^{-42}\},$$
$$\{9.3, 5.7412\times10^{-42}\}, \{9.31, 5.75511\times10^{-42}\}, \{9.32, 5.76904\times10^{-42}\}, \{9.33, 5.78298\times10^{-42}\},$$
$$\{9.34, 5.79694\times10^{-42}\}, \{9.35, 5.81091\times10^{-42}\}, \{9.36, 5.8249\times10^{-42}\}, \{9.37, 5.8389\times10^{-42}\},$$
$$\{9.38, 5.85292\times10^{-42}\}, \{9.39, 5.86695\times10^{-42}\}, \{9.4, 5.881\times10^{-42}\}, \{9.41, 5.89507\times10^{-42}\},$$
$$\{9.42, 5.90915\times10^{-42}\}, \{9.43, 5.92325\times10^{-42}\}, \{9.44, 5.93736\times10^{-42}\}, \{9.45, 5.95149\times10^{-42}\},$$
$$\{9.46, 5.96563\times10^{-42}\}, \{9.47, 5.97979\times10^{-42}\}, \{9.48, 5.99396\times10^{-42}\}, \{9.49, 6.00815\times10^{-42}\},$$
$$\{9.5, 6.02236\times10^{-42}\}, \{9.51, 6.03658\times10^{-42}\}, \{9.52, 6.05082\times10^{-42}\}, \{9.53, 6.06507\times10^{-42}\},$$

$$\{9.54, 6.07934\times10^{-42}\}, \{9.55, 6.09362\times10^{-42}\}, \{9.56, 6.10792\times10^{-42}\}, \{9.57, 6.12223\times10^{-42}\},$$
$$\{9.58, 6.13656\times10^{-42}\}, \{9.59, 6.15091\times10^{-42}\}, \{9.6, 6.16527\times10^{-42}\}, \{9.61, 6.17964\times10^{-42}\},$$
$$\{9.62, 6.19404\times10^{-42}\}, \{9.63, 6.20844\times10^{-42}\}, \{9.64, 6.22286\times10^{-42}\}, \{9.65, 6.2373\times10^{-42}\},$$
$$\{9.66, 6.25176\times10^{-42}\}, \{9.67, 6.26622\times10^{-42}\}, \{9.68, 6.28071\times10^{-42}\}, \{9.69, 6.29521\times10^{-42}\},$$
$$\{9.7, 6.30972\times10^{-42}\}, \{9.71, 6.32425\times10^{-42}\}, \{9.72, 6.3388\times10^{-42}\}, \{9.73, 6.35336\times10^{-42}\},$$
$$\{9.74, 6.36794\times10^{-42}\}, \{9.75, 6.38253\times10^{-42}\}, \{9.76, 6.39714\times10^{-42}\}, \{9.77, 6.41176\times10^{-42}\},$$
$$\{9.78, 6.4264\times10^{-42}\}, \{9.79, 6.44105\times10^{-42}\}, \{9.8, 6.45572\times10^{-42}\}, \{9.81, 6.47041\times10^{-42}\},$$
$$\{9.82, 6.48511\times10^{-42}\}, \{9.83, 6.49982\times10^{-42}\}, \{9.84, 6.51455\times10^{-42}\}, \{9.85, 6.5293\times10^{-42}\},$$
$$\{9.86, 6.54406\times10^{-42}\}, \{9.87, 6.55884\times10^{-42}\}, \{9.88, 6.57363\times10^{-42}\},$$
$$\{9.89, 6.58843\times10^{-42}\}, \{9.9, 6.60326\times10^{-42}\}, \{9.91, 6.6181\times10^{-42}\}, \{9.92, 6.63295\times10^{-42}\},$$
$$\{9.93, 6.64782\times10^{-42}\}, \{9.94, 6.6627\times10^{-42}\}, \{9.95, 6.6776\times10^{-42}\}, \{9.96, 6.69252\times10^{-42}\},$$
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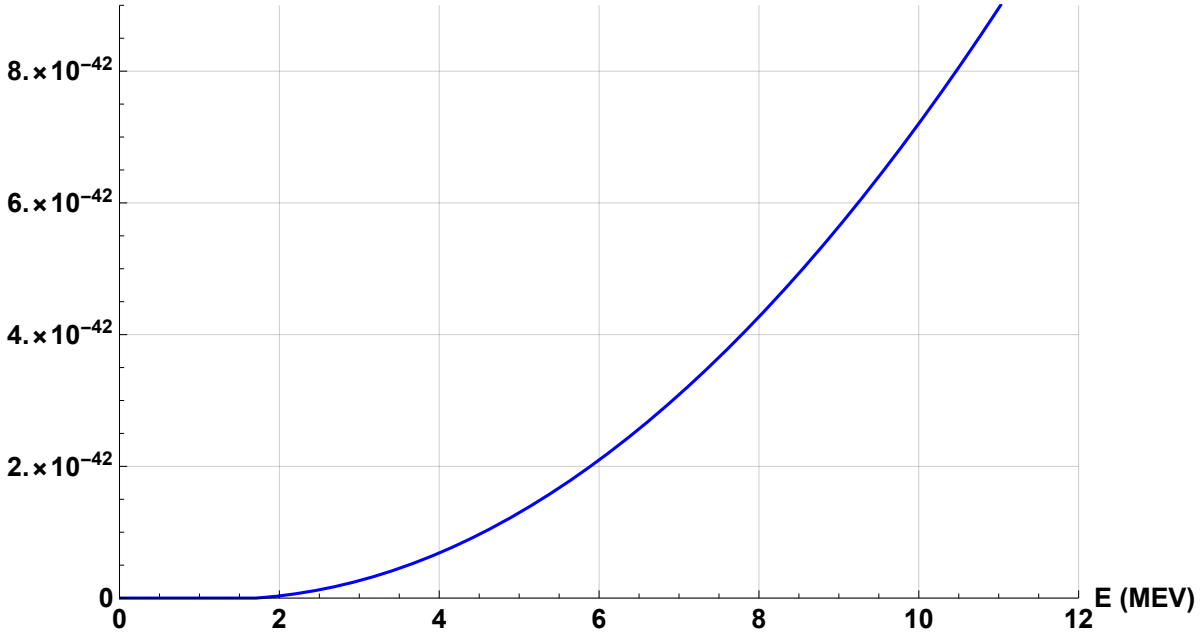
$$\{19.38, 2.69334\times10^{-41}\}, \{19.39, 2.69608\times10^{-41}\}, \{19.4, 2.69882\times10^{-41}\},$$
$$\{19.41, 2.70157\times10^{-41}\}, \{19.42, 2.70431\times10^{-41}\}, \{19.43, 2.70706\times10^{-41}\},$$
$$\{19.44, 2.7098\times10^{-41}\}, \{19.45, 2.71255\times10^{-41}\}, \{19.46, 2.7153\times10^{-41}\},$$
$$\{19.47, 2.71805\times10^{-41}\}, \{19.48, 2.7208\times10^{-41}\}, \{19.49, 2.72355\times10^{-41}\},$$
$$\{19.5, 2.72631\times10^{-41}\}, \{19.51, 2.72906\times10^{-41}\}, \{19.52, 2.73182\times10^{-41}\},$$
$$\{19.53, 2.73457\times10^{-41}\}, \{19.54, 2.73733\times10^{-41}\}, \{19.55, 2.74009\times10^{-41}\},$$
$$\{19.56, 2.74285\times10^{-41}\}, \{19.57, 2.74561\times10^{-41}\}, \{19.58, 2.74837\times10^{-41}\},$$
$$\{19.59, 2.75114\times10^{-41}\}, \{19.6, 2.7539\times10^{-41}\}, \{19.61, 2.75667\times10^{-41}\},$$
$$\{19.62, 2.75943\times10^{-41}\}, \{19.63, 2.7622\times10^{-41}\}, \{19.64, 2.76497\times10^{-41}\},$$
$$\{19.65, 2.76774\times10^{-41}\}, \{19.66, 2.77051\times10^{-41}\}, \{19.67, 2.77328\times10^{-41}\},$$
$$\{19.68, 2.77606\times10^{-41}\}, \{19.69, 2.77883\times10^{-41}\}, \{19.7, 2.78161\times10^{-41}\},$$
$$\{19.71, 2.78438\times10^{-41}\}, \{19.72, 2.78716\times10^{-41}\}, \{19.73, 2.78994\times10^{-41}\},$$
$$\{19.74, 2.79272\times10^{-41}\}, \{19.75, 2.7955\times10^{-41}\}, \{19.76, 2.79828\times10^{-41}\},$$
$$\{19.77, 2.80107\times10^{-41}\}, \{19.78, 2.80385\times10^{-41}\}, \{19.79, 2.80664\times10^{-41}\},$$
$$\{19.8, 2.80942\times10^{-41}\}, \{19.81, 2.81221\times10^{-41}\}, \{19.82, 2.815\times10^{-41}\},$$
$$\{19.83, 2.81779\times10^{-41}\}, \{19.84, 2.82058\times10^{-41}\}, \{19.85, 2.82337\times10^{-41}\},$$
$$\{19.86, 2.82617\times10^{-41}\}, \{19.87, 2.82896\times10^{-41}\}, \{19.88, 2.83176\times10^{-41}\},$$
$$\{19.89, 2.83455\times10^{-41}\}, \{19.9, 2.83735\times10^{-41}\}, \{19.91, 2.84015\times10^{-41}\},$$
$$\{19.92, 2.84295\times10^{-41}\}, \{19.93, 2.84575\times10^{-41}\}, \{19.94, 2.84855\times10^{-41}\},$$
$$\{19.95, 2.85136\times10^{-41}\}, \{19.96, 2.85416\times10^{-41}\}, \{19.97, 2.85697\times10^{-41}\},$$
$$\{19.98, 2.85977\times10^{-41}\}, \{19.99, 2.86258\times10^{-41}\}, \{20., 2.86539\times10^{-41}\}\}$$

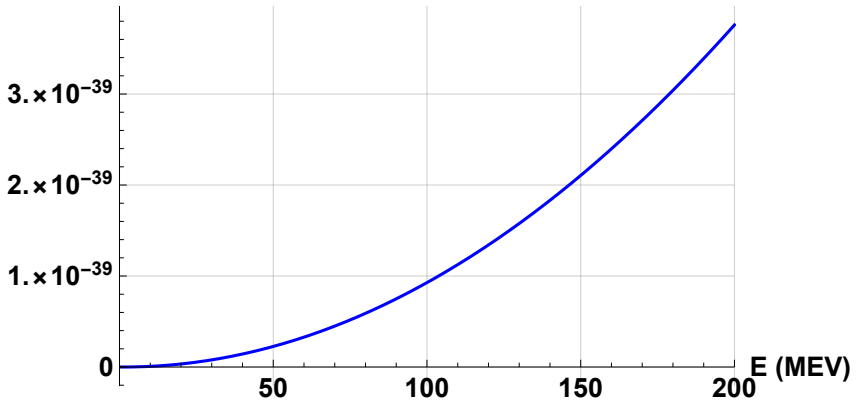
In[•]:=
```
ibd0 = Plot[CrossSection0[x], {x, 0, 12}, PlotStyle → Blue,
  AxesStyle → Directive[Bold, 14], PlotRange → {{0, 12}, {0, 9 * 10^-42}},
  GridLines → Automatic, AxesLabel → {"E (MEV)", " "}]
```

Out[•]=

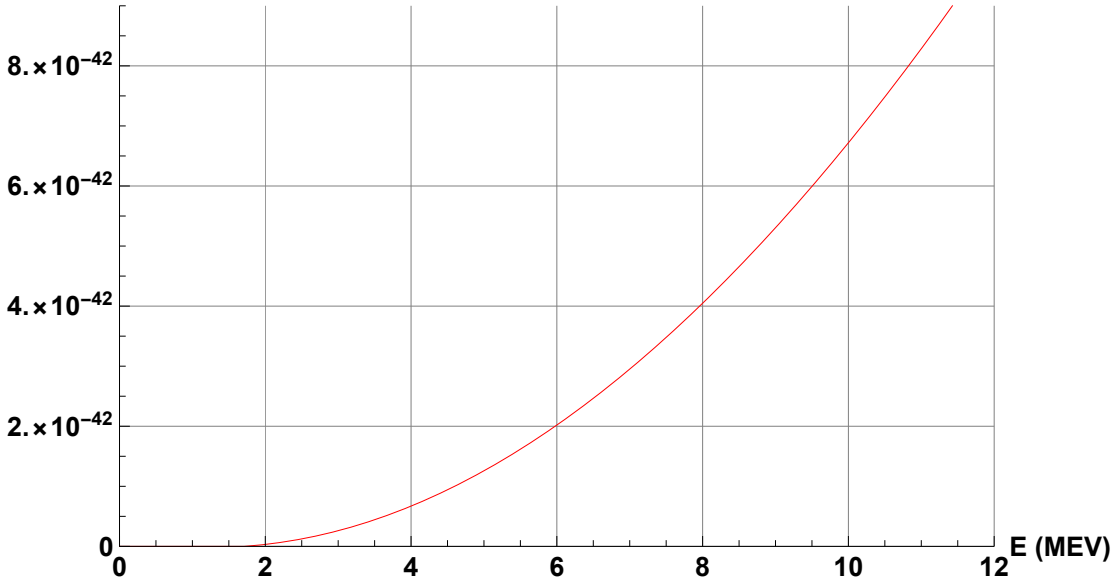


In[•]:=
```
ibd200 = Plot[CrossSection0[x], {x, 0, 200}, PlotStyle → Blue,
  AxesStyle → Directive[Bold, 14], PlotRange → {{0, 200}, Automatic},
  GridLines → Automatic, AxesLabel → {"E (MEV)", " "}]
```

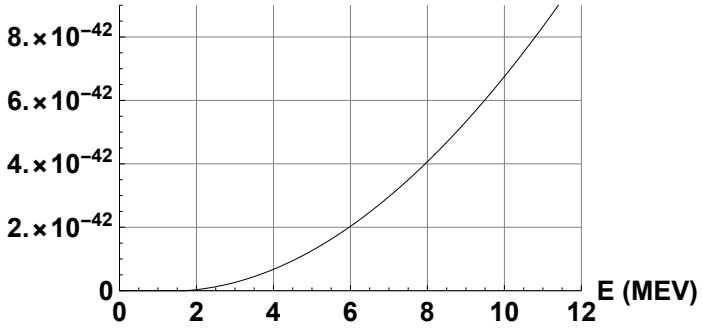
Out[•]=



```
ibdnlo = Plot[CrossSection1[x, 885.7, 1.26], {x, 0, 12}, PlotStyle → Red,
  AxesStyle → Directive[Bold, 14], PlotRange → {{0, 12}, {0, 9 * 10^-42}},
  GridLines → Automatic, AxesLabel → {"E (MEV)", " "}]
```



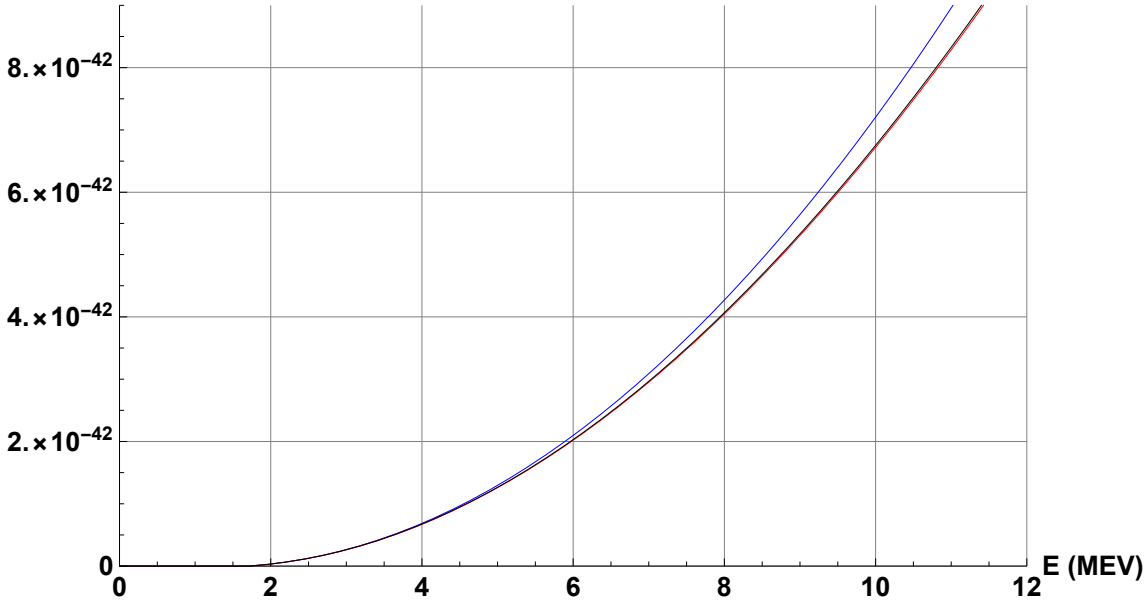

```
ibdnlopdg = Plot[CrossSection1[x, 881.5, 1.2701], {x, 0, 12}, PlotStyle → Black,
  AxesStyle → Directive[Bold, 14], PlotRange → {{0, 12}, {0, 9 * 10^-42}},
  GridLines → Automatic, AxesLabel → {"E (MEV)", " "}]
```



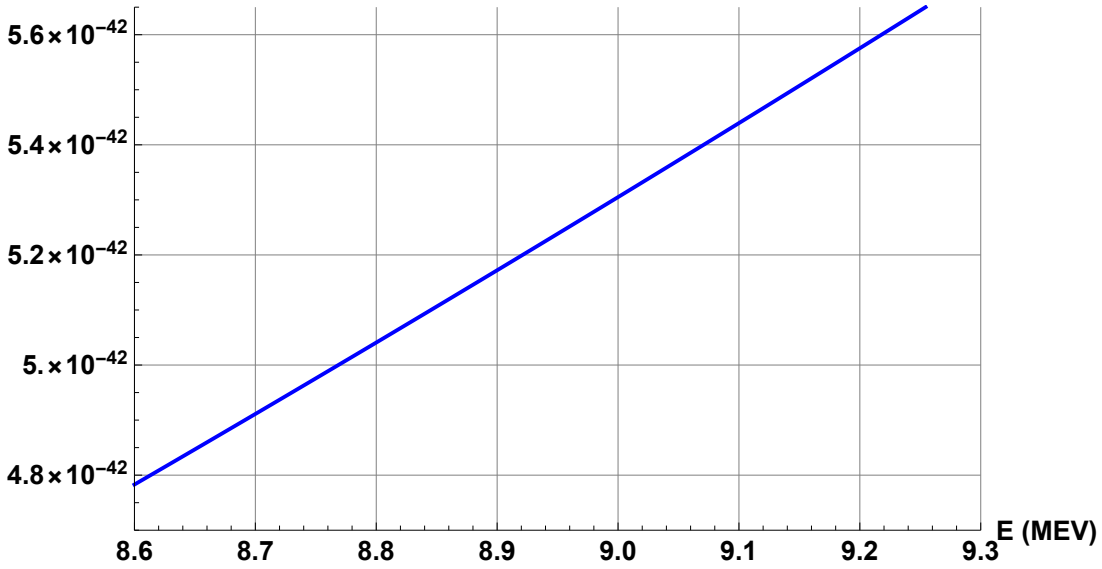
In[•]:= `CrossSection1[200, 881.5, 1.2701]`

Out[•]= -1.76828×10^{-39}

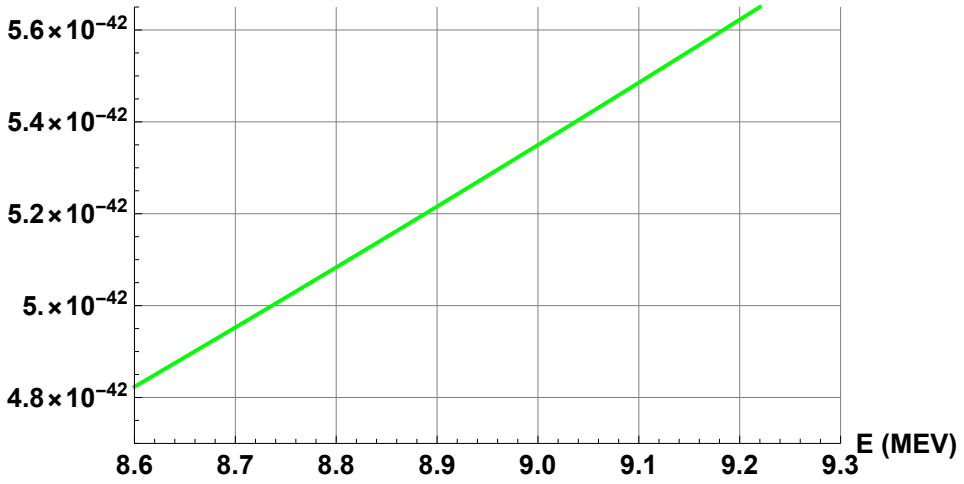
```
Show[ibd0, ibdnlo, ibdnlopdg]
```



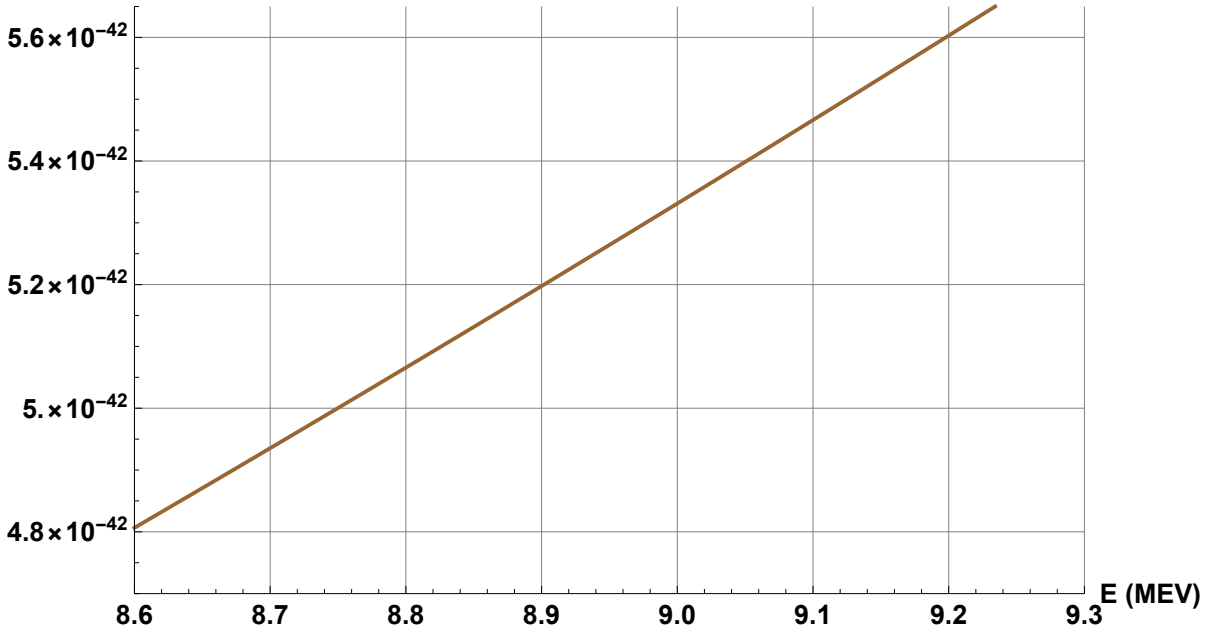

```
idb1 =  Plot[CrossSection1[x, 885.7, 1.26], {x, 8.6, 9.3},
  PlotStyle → {Blue, Thick}, AxesStyle → Directive[Bold, 14],
  PlotRange → {{8.6, 9.3}, {4.7 * 10^-42, 5.65 * 10^-42}},
  GridLines → Automatic, AxesLabel → {"E (MEV)", " "}]
```



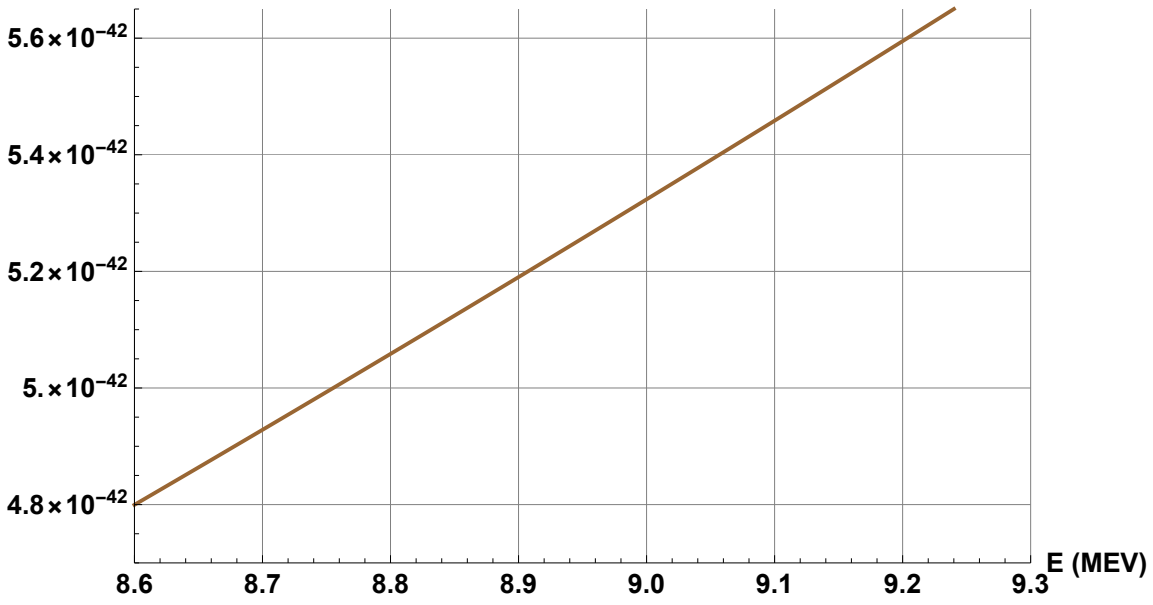
```
idb2serliu = Plot[CrossSection1[x, 878.5, 1.2759], {x, 8.6, 9.3},
  PlotStyle → {Green, Thick}, AxesStyle → Directive[Bold, 14],
  PlotRange → {{8.6, 9.3}, {4.7 * 10^-42, 5.65 * 10^-42}},
  GridLines → Automatic, AxesLabel → {"E (MEV)", " "}]
```




```
ibd6 = Plot[CrossSection1[x, 881.5, 1.2701], {x, 8.6, 9.3},
  PlotStyle → {Brown, Thick}, AxesStyle → Directive[Bold, 14],
  PlotRange → {{8.6, 9.3}, {4.7 * 10^-42, 5.65 * 10^-42}},
  GridLines → Automatic, AxesLabel → {"E (MEV)", " "}]
```



```
ibd6fin = Plot[CrossSection1[x, 881.5, 1.2701], {x, 8.6, 9.3},
  PlotStyle → {Brown, Thick}, AxesStyle → Directive[Bold, 14],
  PlotRange → {{8.6, 9.3}, {4.7 * 10^-42, 5.65 * 10^-42}},
  GridLines → Automatic, AxesLabel → {"E (MEV)", " "}]
```




```
Show[idb1, ibd6, idb2serliu]
```

