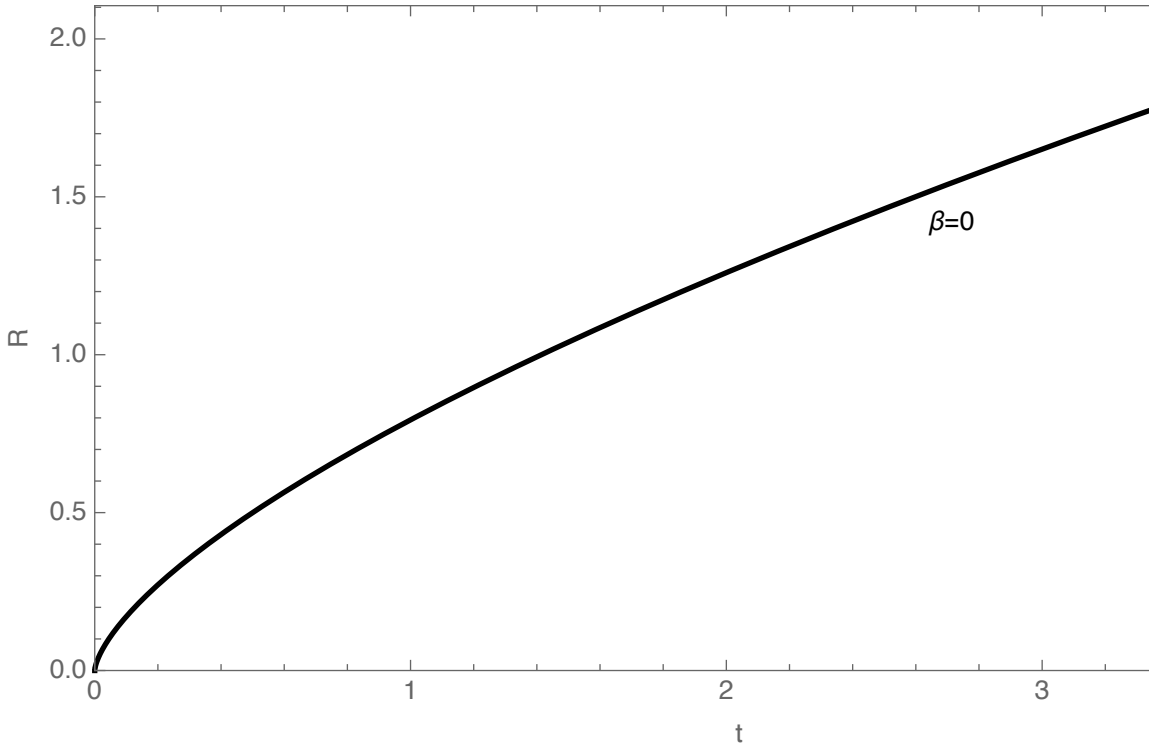
Cosmology, Problem 1: Evolution of Universe with general Energy of Particles

Problem 4. Parametric plot:
$\gamma(\eta) = (R(\eta), t(\eta))$.
Case $\beta = 0$ $(E = 0)$

In[1]:=
```
params = {α → 1, β → 1};
```

In[2]:=
```
figPlotE0 = ParametricPlot[(α/2 {η^3, η^2}) /. params,
  {η, 0, 2}, PlotRange → {{0, 4}, {0, 2}},
  PlotStyle → {Black, Thick},
  Frame → True,
  (*PlotLabel→"Evolution of R(t) (E=0)",*)
  FrameLabel → {"t", "R"},
  LabelStyle → (FontFamily → "Helvetica"),
  PlotLabels → Placed[{"β=0"}, Scaled[0.7]]]
```

Out[2]=

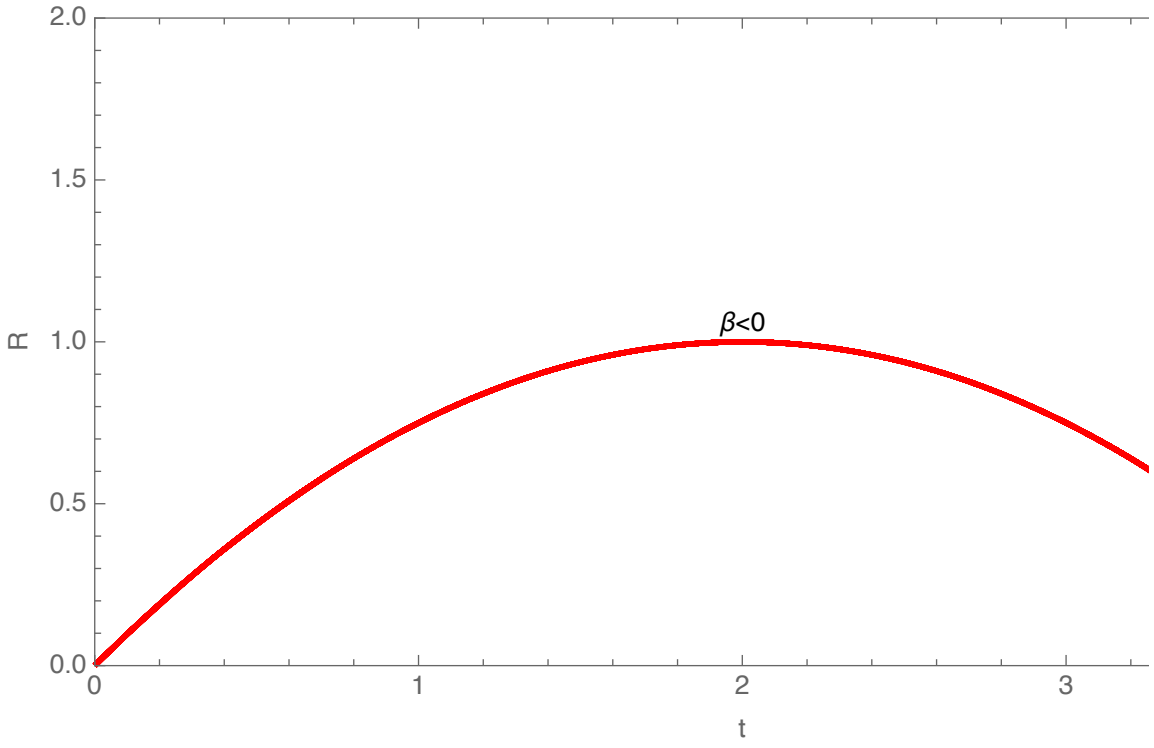


In[3]:= Case $\beta < 0$ ($E < 0$)

Out[3]= Case $\beta < 0$

In[4]:=
```
figPlotEN =
  ParametricPlot[
   ((α/β) {2 + 2/Sqrt[β] Sin[Sqrt[β]/2 η], Cos[Sqrt[β]/2 η]^2}) /.
    params, {η, -100, 100}, PlotRange → {{0, 4}, {0, 2}},
   PlotStyle → {Red, Thick},
   Frame → True,
   (*PlotLabel→"Evolution of R(t) (E<0)",*)
   FrameLabel → {"t", "R"},
   LabelStyle → (FontFamily → "Helvetica"),
   PlotLabels → Placed[{"β<0"}, Above]]
```

Out[4]=

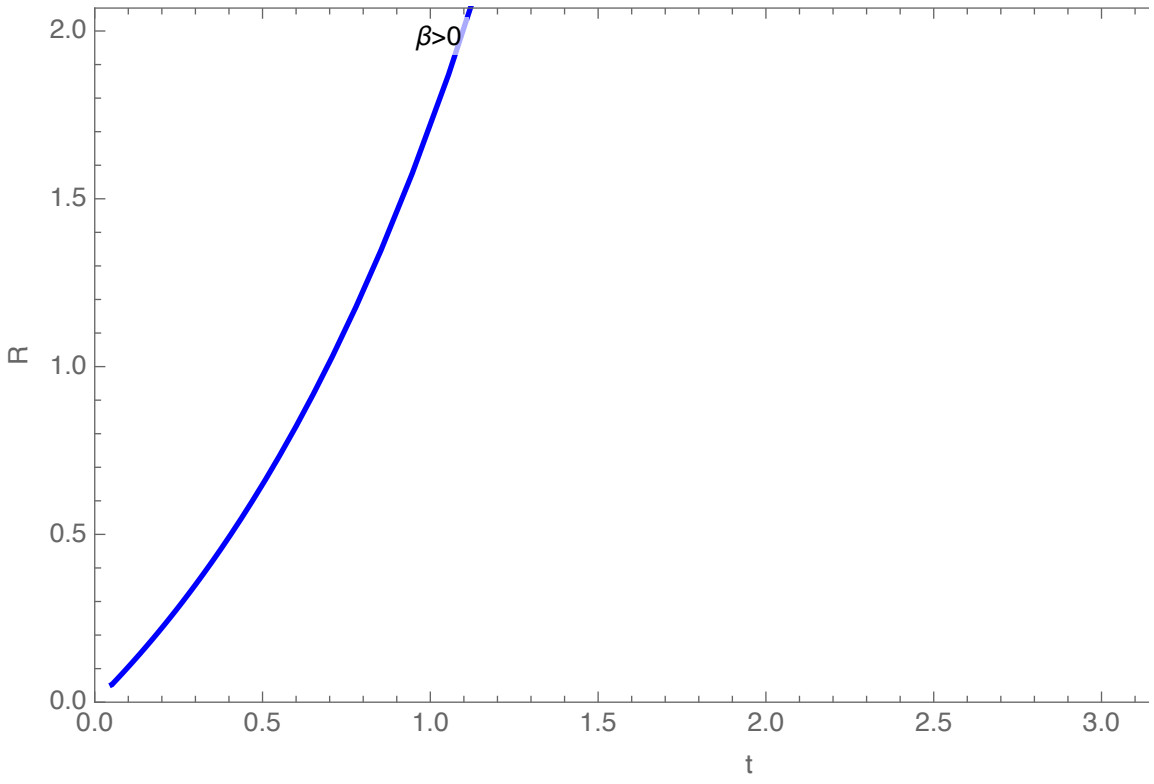


In[5]:= Case $\beta > 0$ ($E > 0$)

Out[5]= Case $\beta > 0$

In[6]:=
```
figPlotEP =
  ParametricPlot[
   ({-(Log[1 - β Exp[α η]]/β), (α Exp[α η])/(1 - β Exp[α η])}) /. params,
   {η, -3, 0}, PlotRange → {{0, 3.9}, {0, 2}},
   PlotStyle → {Blue, Thick},
   Frame → True,
   (*PlotLabel→"Evolution of R(t) (E>0)"*)
   FrameLabel → {"t", "R"},
   LabelStyle → (FontFamily → "Helvetica"),
   PlotLabels → Placed[{"β>0"}, Above]]
```

Out[6]=



Putting everything together

In[7]:=
```
Show [figPlotE0, figPlotEN, figPlotEP]
```

Out[7]=