Quasi-Secondary Submodules

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Abstract

Let \( R \) be a commutative ring with non-zero identity and \( M \) be a unitary \( R \)-module. Then the concept of quasi-secondary submodules of \( M \) is introduced and some results concerning this class of submodules is obtained.

1. Introduction

Throughout this paper all rings are commutative with non-zero identity and all modules are unitary. In [4] L. Fuchs introduced and studied the concept of quasi-primary ideals (see also [5]). An ideal \( I \) of a ring \( R \) is called a quasi-primary ideal of \( R \) if the radical of \( I \) is a prime ideal of \( R \). This concept then generalized to modules, i.e., the concept of quasi-primary submodules of a module introduced and developed in [3]. Here, we introduce the dual notation, that is, the quasi-secondary submodules of a module and obtain some results concerning this class of submodules. In section 2, we obtain some preliminary properties of quasi-secondary submodules. Section 3 is devoted to the quasi-secondary submodules of a multiplication module. Now we define some concepts which will be needed in sequel.

Let \( M \) be an \( R \)-module and \( N \) a submodule of it. The ideal \( \{ r \in R \mid rM \subseteq N \} \) will be denoted by \((N_R^M)\); in particular \((0_R^M)\) is called the annihilator of \( M \). A non-zero submodule \( N \) of \( M \) is called a secondary (resp. second) submodule of \( M \) if for each \( r \in R \) the homothety \( N \xrightarrow{r} N \) is surjective or nilpotent (resp. surjective or zero). In this case \( \sqrt{(0_R^N)} \) is a prime ideal, say \( p \), and we call \( N \) a \( p \)-secondary (resp. \( p \)-second) submodule of \( M \). We refer readers for more details concerning secondary (resp. second) submodules to [9] (resp. [12]).

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An R-module $M$ is said to be a multiplication module if for each submodule $N$ of $M$ there exists an ideal $I$ of $R$ such that $N = IM$. It is easy to see that in this case $N = (N, M)M$. Also the ideal $\theta(M)$ is defined as $\theta(M) : = \sum_{m \in M} (Rm, M)$. If $M$ is a multiplication module and $N$ is a submodule of it, then $M = \theta(M)M$ and $N = \theta(M)N$. (see [1]). An R-module $M$ is sum-irreducible if $M \sqsupsetneq 0$ and the sum of any two proper submodules of $M$ is always a proper submodule. Finally a proper submodule $N$ of an R-module $M$ is called a prime submodule if for each $r \in R$ the homothety $M/N \xrightarrow{r} M/N$ is either injective or zero. This implies that $\text{Ann}(M/N) = p$ is a prime ideal of $R$, and $N$ is said to be a p-prime submodule (c.f. [7], [8], [10] and [11]).

2. Quasi-Secondary Submodules

The starting point of this section is the definition of quasi-secondary submodules of a module.

Definition 2.1. Let $M$ be a non-zero R-module. Then the non-zero submodule $N$ of $M$ is said to be quasi-secondary if $\sqrt{(0, R^2)} = p$ where $p$ is a prime ideal of $R$. It is obvious that every secondary (or second) submodule of a module is a quasi-secondary submodule, but the converse is not true in general. For example, $2Z$ is a 0-quasi-secondary submodule of the Z-module $Z$ but it is not 0-secondary (or 0-second) submodule. (Here $Z$ denotes the set of all integers.)

Remark 2.2.

(i) Let $M$ be a non-zero R-module and $N$ a submodule of it such that $\sqrt{(0, R^2)} = m(m \in \text{Max} (R))$. Then $N$ is $m$-secondary ($m$-second).

(ii) Every quasi-secondary submodule of a module over a zero-dimentional ring (i.e., a ring in which every prime ideal is a maximal ideal) is secondary.

(iii) Every quasi-secondary submodule of a module over a D.V.R is secondary.

Definition 2.3. Let $M$ be an R-module and $N$ a submodule of $M$. An element $r$ of $R$ is called co-primal to $N$ if $rN = N$. Denote by $W(N)$ the set of all elements of $R$ that are not co-primal to $N$. The submodule $N$ is said to be a co-primal submodule of $M$ if $W(N)$ is an ideal of $R$. This ideal is always a prime ideal. In this case we say that $N$ is a p-co-primal submodule of $M$. The class of co-primal submodules of a module is a
fairly large class. For example, all secondary (second) submodules are co-primal. Also it is easy to see that a sum-irreducible submodule of a module is co-primal. But, in general, a quasi-secondary submodule of a module may not be a co-primal submodule. (consider the $\mathbb{Z}$-module $\mathbb{Z}$.) It is worth to mention that in [2] the term secondal is used for co-primal submodules. The next proposition characterizes those $p$-quasi-secondary submodules which are $p$-co-primal.

Proposition 2.4. Let $N$ be a $p$-quasi-secondary submodule of an $R$-module $M$. Then $N$ is a $p$-co-primal submodule of $M$ if and only if it is a $p$-secondary submodule of $M$.

Proof $\Rightarrow$ Let $N \rightarrow N$ be the $R$-endomorphism of $N$ given by multiplication by $r$ of $R$ and $rN \neq N$. Then by our assumption $r \in p = \{ s \in R | s \neq N \}$. On the other hand, $p = \sqrt{0_R}N$ and so there exists a positive integer $t$ such that $r^t N = 0$. The result follows.

\[ \Leftrightarrow \] Is obvious.

The proof of two next propositions is easy and so we state them without proof.

Proposition 2.5. Let $M$ be a module over an integral domain and $N$ be a $0$-co-primal submodule of $M$. Then $N$ is $0$-secondary.

Proposition 2.6. Let $M$ be an $R$-module and $N_1, N_2, \ldots, N_t$ be submodules of $M$. Then
(i) Suppose that for $i = 1, 2, N_i$ is $p_i$-quasi-secondary. Then $N_1 + N_2$ is quasi-secondary if and only if $p_1 \subseteq p_2$ or $p_2 \subseteq p_1$.
(ii) If $N_1, \ldots, N_t$ are $p$-quasi-secondary, then $N_1 + \cdots + N_t$ is a $p$-quasi-secondary submodule of $M$.
(iii) If $N_1 + \cdots + N_2$ is a $p$-quasi-secondary submodule of $M$. Then $N_j$ is $p$-quasi-secondary for some $j, 1 \leq j \leq t$.

3. Multiplication Modules

In this short section we give a property of quasi-secondary submodules of a multiplication module.

Lemma 3.1. Let $M$ be a multiplication module and $N$ be a $p$-quasi-secondary submodule of $M$. Then $\theta(M) \nsubseteq p$.

Proof. Suppose that $\theta(M) \subseteq p$ and $0 \neq n \in N$. Then $Rn = \theta(M)Rn \subseteq pn$. Hence $n = p_0n$ for some $p_0 \in p$. By our assumption there exists a positive integer $t$ such that $p_0^t N = 0$. Therefore $n = p_0^t n = 0$, a contradiction.
Theorem 3.2. Suppose that $M$ is a faithfull multiplication module and $N$ a $p$-quasi-secondary submodule of $M$. Then $pM$ is a prime submodule of $M$. In particular, if $p \in \text{max}(R)$, then $pM$ is a maximal submodule of $M$.

Proof. By Lemma 3.1, $\theta(M) \nsubseteq p$. Now suppose that $pM = M = RM$. Then by [1, Theorem 1.5] $R \cap \theta(M) = \theta(M) = p \cap \theta(M)$ and hence $\theta(M) \subseteq p$ which is a contradiction. Thus $pM \neq M$ and the result of the first part follows from [6, Lemma 2.4(2)]. The last part can be deduced from the first part and [6, Corollary 2.7].

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References